BLOOD SUPPLY AND ANATOMY
of the
UPPER ABDOMINAL ORGANS

With a Descriptive Atlas

Blood Supply and Anatomy

of the

Upper Abdominal Organs

With a Descriptive Atlas

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172 ILLUSTRATIONS, INCLUDING 166 IN COLOR

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To my wife

HILDA DAVEY MICHELS

for her real help

this book is

affectionately inscribed

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when
We gloriously forget ourselves and plunge
Soul forward headlong into a book's profound
Impassioned for its beauty and salt of truth—
'Tis then we get the right good from a book

—ELIZABETH BARRETT BROWNING

Preface

Publication of this descriptive atlas is long overdue a fact well known by anatomists and surgeons both here and abroad who have studied the drawings and examined the specimens from which they were made Causes for the delay of publication have been many and diverse a protracted one being the time and the work expended in preparing the drawings for color reproduction and in writing a text which would be not only descriptive but also informative as to the manner in which arterial variations arise and as to the regional anatomic changes that are effected by their presence

Experienced and successful surgeons realize that with a wide basic knowledge of anatomy and embryology both normal and aberrant they are never at a loss when operating that the best way to avoid exsanguinating hemorrhage and to prevent ischemia gangrene and postoperative disconcerting bleeding is to know the blood vessels and how to manipulate and ligate them properly as so forcefully taught by Dr William Stewart Halsted This great pioneer American surgeon (1852–1922) is to be remembered not only as the first to have introduced rubber gloves in surgery (1890) but also as the one who stated that The surgeon's method of dealing with the blood vessels is a criterion of his proficience in his art (1921)

My interest in arterial variations was aroused first by a study of the splenic artery (1942) Dissection of 100 bodies revealed the fact that the pattern of terminal branching of the splenic artery is never the same and that every spleen presents decided differences as regards its morphology and its mode of arterial vascularization The interest aroused in the investigative work on splenic vascularization encouraged me to investigate in like manner the arterial blood supply of all of the upper abdominal organs in a sample of 100 bodies Variations being more pronounced than anticipated another 100 bodies were dissected before I attempted generalizations and conclusions The magnitude of the work of detailed dissection the recording with accurate drawings the uncertainty as to the mode of presentation the publication of final results—all this has meant that nearly 20 years of my research life have been spent in the preparation of this atlas

Often during the progress of the book when the ideal aimed at seemed to be unattainable when the effort expended gave little reward when variation after variation baffled classification and interpretation my enthusiasm dropped to a low level—sufficiently low in some instances to give rise to the thought of abandoning in despair the entire project It was at such times that many prominent surgeons (local national and international) came to my aid with the plea that a descriptive atlas on arterial variations of the upper abdominal organs as contemplated was needed urgently

The mode of the intrahepatic distribution of the hepatic arteries and bile

I wish to express my thanks for the opportunity given me to undertake this work and for the interest he showed in it

To Dr George Allen Bennett Dean of Jefferson Medical College Professor of Anatomy and Director of the Daniel Baugh Institute of Anatomy I wish to extend an acknowledgment of appreciation and grateful thanks for his suggestions as to the anatomic import of the topics discussed and for the interest taken during the course of the work Such appreciation and grateful thanks likewise are due to Dr Thomas A Shallow and to Dr John H Gibbon Jr of the Department of Surgery of Jefferson Medical College Dr Shallow was the first surgeon to have examined with stimulating comment my initial 50 specimens showing in detail the varied blood supply of the biliary system Dr Gibbon graciously entered my statistical analysis of the variational anatomy of the hepatic and cystic arteries as observed in 200 bodies in the *Annals of Surgery* of which he is Editor

Not for personal aggrandizement or glory but as recognition of an achievement made possible through the persistent—at times hopeless and forlorn—efforts on my part for 20 years I wish to record a few lines written to me in his own handwriting by the eminent British surgeon Sir Arthur Keith * at the age of 88 a few months before his death (January 7 1955) I am most grateful to you for the thorough and complete enquiry you have made on the arterial blood supply of the human liver a model for other anatomists to copy

Special thanks and indebtedness for the information and the illustrations on the segmental division of the liver and on the intrahepatic distribution of bile ducts and the hepatic arteries as revealed in plastic casts are due to Dr John F Healey Jr former Assistant Professor of Anatomy at the Daniel Baugh Institute of Anatomy and senior author of the papers published by Drs Healey and Schroy and to Paul C Schroy Ph D a graduate student in the department of anatomy under my sponsorship who initially undertook the problem of investigating the bile ducts inside the liver as the subject of his doctorate thesis It was at my suggestion that the problem of investigating the intrahepatic distribution of bile ducts and arteries in plastic casts was undertaken by Drs Healey and Schroy not knowing at the time when the investigation was under way of the work of Hjortsjo in Sweden on the segmentation of the liver In the 2 articles that have been published by Drs Healey and Schroy the text was written under my supervision by Dr Healey who made all the roentgenograms and ultimately determined the nomenclature that was used In his doctorate thesis (The Intrahepatic Distribution of the Bile Ducts Within the Human Liver June 1953) Dr Schroy extended the investigation of the intrahepatic bile ducts to those of the fourth order as illustrated in Figure 6 of this atlas

In view of their anatomic significance and their importance in regional surgery (cholecystectomy bile duct repair and partial hepatectomy) 12 samples of Schroy s dissections of the extrahepatic tributaries to the common hepatic duct have been included especially since no comparable figures on terminal emerging hepatic bile ducts are to be found in any text of anatomy or surgery

As final items in the atlas and to afford a general concept of the venous vascularization of the liver of effective informative value in liver resections and transections an illustration of the intra

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* Sir Arthur Keith Hunterian Professor of Anatomy College of Surgeons London England was elected an honorary member of the American Association of Anatomists at its 32nd Session at Yale University New Haven December 28-30 1915

ducts as ascertained by Drs Healey and Schroy in their 150 corrosion vinyl acetate casts of human livers made at the Daniel Baugh Institute of Anatomy of Jefferson Medical College is presented in detail in view of its significance as *the first statistical analysis of the intrahepatic branches* and its clinical significance in partial hepatectomies In view of the newer investigative results obtained in living animals the intrasplenic circulation has been emphasized A comparative anatomy of the spleen has been included to offset the dangers of drawing unjustifiable sweeping conclusions from animal experimentations A short survey of the comparative anatomy of the biliary apparatus from fish to man has been made to account for the presence and to give a phylogenetic explanation of the anomalies encountered so frequently in biliary surgery A concept *of hepatoscopy as practiced in antiquity* and data on the history of the first cholecystectomy in America have been included as being of interest to anatomists and surgeons alike

As a persistent guide items have been selected and discussed in such a manner as to give the average surgeon a sense of anatomic security when operating It is felt that younger men as they replace their predecessors who are relatively more widely experienced in upper abdominal surgery can attain this sense of security more quickly and more systematically with the aid of an atlas in which are portrayed the anatomy of the variable individuals met with in daily surgical practice as well as the developmental reasons for such constitutional variations

In addition considerable thought time and effort were expended in presenting the essential items on embryology topographic relations developmental anomalies and routes of collateral circulation that every abdominal surgeon should know The recording of the 26 possible routes of collateral circulation to the liver is the first that has ever been made

All the large regionally complete drawings were made by Vincent Nast to whom I owe gratitude and deep appreciation for the innumerable hours of painstaking labor that he as a friend devoted to this work In every instance he outlined his final drawing after studying the actual specimen and after identifying the nature and the course of the arteries which I previously had sketched in pencil at dissection Without his devoted interest and enthusiastic support my large pencil sketches in all probability never would have been redrawn for publication to the excellent extent that they have been nor would the exhibit I presented at the Centennial Meeting of the American Medical Association at Atlantic City June 9–13 1947 and the exhibit I gave in Rome before the Sixth *International Congress of the International* College of Surgeons May 16–24 1948 at the gracious invitation of Dr Max Thorek have had the explanatory charts executed as accurately and as neatly as they were

The small schematic drawings were made by V Huppi several of the larger charts including the key labeled drawing were made by R Demarest The outline figures on the celiac variants were drawn by Gloria Green Hirsch and Vincent Nast Marguerite Caudin made 4 large drawings and Betty Minter the first to assist me in my work made all the original drawings on the splenic artery *and the spleen* Several drawings of the spleen and one on the liver were redrawn by Marie Regan The main frontal design figure was made by William B McNett a pupil of Brodel s To these artists I extend my thanks and my appreciation

To Dr J Parsons Schaeffer Professor of Anatomy Emeritus and former Director of the Daniel Baugh Institute of Anatomy of Jefferson Medical College

Contents

hepatic distribution of the portal vein and one of the hepatic vein have been added This was done not as an afterthought but because the work containing these illustrations (which is based on the vinyl acetate liver casts of Healey and Schroy) was written and published by Healey (*J Internat Coll Surgeons* 22 542 1954) after the author had completed the writing of the chapter on the liver

My sincere thanks are due to Dr Andrew Jackson Ramsay for his critical reading of the text on embryologic items and in particular for the splendid photographic records he made of my drawings for presentations at anatomic and surgical meetings Cordial thanks are due to Dr Leslie B Arey Professor of Anatomy at Northwestern University Medical School for the helpful suggestions that he offered in his review of the chapter on Embryology Topographic Relations and Developmental Anomalies To Dr Leandro M Tocantins I wish to express my thanks for his critical reading of the chapter on the spleen Thanks and appreciation likewise are due to Dr Justus Ohage Jr of St Paul Minn to the publishers of *Minnesota Medicine* for allowing me to reprint the historic article on cholecystectomy and to Dr Frederick Schuldt our family physician and surgeon for many years who made me aware of this work

To the American Philosophical Society I wish to express my special thanks and appreciation for several grants extended to help defray the expenses of having artists prepare many of my large drawings for publication, and also for the grant extended to Drs Healey and Schroy to cover the expense of printing the illustrations of their first paper

To the staff of J B Lippincott Company who engaged actively in this work —Walter Kahoe J Brooks Stewart Stanley A Gillet Laura E Moore and Edwin Bookmyer—I wish to record my great pleasure and deep appreciation for their painstaking effort and patience in preparing the atlas in its present form

To Miss Myrtle Bremerman, secretary at the Daniel Baugh Institute for many years I extend my thanks for her exact neat corrective typing of the manuscript and such thanks likewise are extended to Miss C Sargeant for her assistance in typing

A final word of thanks and deep appreciation is hereby extended to my dear wife who constantly upheld my spirit during the progress of this tedious work incessantly urged me to get it into print and helped me in the color preparation of the illustrations and in reading of the proof

NICHOLAS A MICHELS
Philadelphia

Blood Supply and Anatomy of the Upper Abdominal Organs

The surgeon s method of dealing with the blood vessels is a criterion of his proficiency in his art The moment of tying the ligature is indeed a dramatic one The monstrous looming tumor is stilled by a tiny thread the tempest silenced by the magic wand

—WILLIAM STEWART HALSTED

1

Arterial Variations

The recent intense development of certain fields of abdominal surgery such as cholecystectomy cholangiojejunostomy with partial hepatectomy total and subtotal gastrectomy transthoracic esophagectomy splenectomy pancreaticoduodenal resection for carcinoma of the head of the pancreas ligation of the hepatic and the splenic arteries in the treatment of portal hypertension (Rienhoff 1951) complete removal of the celiac axis for carcinoma of the stomach (Appleby) have made imperative an extensive adequately based illustrated and descriptive atlas whereby surgeons may attain a clearer appreciation and knowledge of the varied blood supply of the upper abdominal organs The conventional textbook description of the regional blood supply is antiquated and far too inaccurate and incomplete to serve as a surgical guide and precaution

Arterial like other anatomic variations cannot be ignored for the risk of ligating the wrong vessel or severing an essential organ sustaining artery along with the dangers of ischemia and gangrene of leaking and bleeding from sites of repair and at anastomotic suture lines are too great Arterial variations are verifiable facts of human constitution that can be observed time and time again They can be estimated statistically by dissection of a large series of bodies and should accordingly be summed up in the lowest common denominators readily available to the anatomist for teaching and to the surgeon as a guide and precaution in operative procedures

Curious indeed is the history of investigative work on arteries The publication of Vesalius s *De Humani Corporis Fabrica* at Basel in June 1543 and which was dedicated and presented to Emperor Charles V on August 4 1543 at Speyer marked the beginning of modern anatomy Since then only four books with colored plates and text on arterial variations as observed in the entire human body have been published They are (1) the *Icones* of Haller the Swiss physiologist and Professor of Medicine at the University of Gottingen written in Latin dedicated to King George II of England and published in 1756 (2) the *Tabulae Arteriarum* of Tiedemann Professor of Anatomy and Physiology at the University of Heidelberg written in Latin and in German and published in 1822 (3) *The Anatomy of the Arteries of the Human Body* by Richard Quain Professor of Anatomy in University College London and Surgeon to University College Hospital published in 1844 (4) *Das Arteriensystem der Japaner* by Adachi Professor of Anatomy at the University of Kyoto published in 1928 With the ex

of various kinds which are liable to occur, such as those which affect the length, position or direction of the vessels. Under that impression I was led to observe these circumstances more closely and finally to open a record of the condition whatever it might be of the more important vessels in a considerable number of cases . . . a record to be made especially with a view to points bearing on practical surgery.

The need of an atlas on the variational anatomy of the celiac artery which supplies the upper abdominal organs was emphasized 200 years ago by Haller, the great Swiss physiologist. In his monumental work on the arteries of the human body, written in Latin and dedicated to King George II of England, he stated that all too frequently authors have followed Vesalius in describing the celiac artery, whereas Vesalius was not so well versed in arterial arrangement as he was in bones and muscles. Haller devoted 8 pages to the celiac axis and in his lecture on this topic made the following comment (February 20, 1746):

> Nulla magna praefatione hic utendum duxi, qui satis manifestum esse persuasus sum, nullam hactenus tolerabilem iconem totius coeliacae arteriae adeo nobilis datam esse, si ab Eustachiana recesseris, cui viscerum vicinarumque defectus obstat, ne perinde utilissima sit, uti est artificiosissima. Deinde ante paucos annos nulla pene hujus arteriae notitia fuit, antequam Waltherus, Winslowus eam declararent. Sequebantur omnes Vesalium, magnum virum, sed in vasorum corporis humanis cognitione non periende perfectum, ut in ossibus musculisque describendis fuit. Ergo ex iconibus quas multas perfectas habebam duas sumsi, quae mihi vedebuntur sufficere explicandae descriptioni hanc ex magno numero cadaverum brevem quantum potui et perspicuam concinnavi.

It was only after completion of the drawings and the major portion of this text that the author of the present book, in reading the literature, became aware of the fact that Haller 200 years ago had voiced the same desire which has been expressed repeatedly by the surgeons of today, to wit, access (i.e., publication of an atlas on the celiac artery, otherwise stated) to the varied blood supply of the supramesocolonic organs.

It is obvious that no one mind can possibly remember all of the arterial variations that have been encountered in any given extensive investigation such as the present, much less recall and correlate all the variations that have been recorded in the literature by previous workers. Technical maneuvers, interpretation and statistical technic in the finding and the description of the arteries supplying liver, gallbladder, stomach, duodenum, pancreas and spleen have varied with nearly every investigator. Because of these facts and because of an inadequacy of sampling and fortuitous diversity, the listing by percentages of anomalous arteries (aberrant and accessory) in the literature is strikingly discrepant and often violently discordant. Despite this situation the author is entirely in accord with the view expressed by Thompson of Canada (1933) that "if anatomic variations are worth knowing at all, they are worth knowing as accurately as possible."

Such accuracy can be obtained best by means of an atlas. Experience has shown the author that both general and fortuitous variations in the anatomic arrangement of the blood vessels of the supramesocolonic organs can best be visualized and remembered in terms of adequately selected and clearly sketched samples. Carefully chosen, logically oriented pictorial records of actual dissections preclude the possibility of error when percentages are computed regarding the nature, the course and the distribution of a given artery; they facilitate verification and, above all, can be used by every subsequent investigator irrespective of the statistical technic or the nomenclature employed.

ception of Adachi who gave an extensive description of the celiac axis and made small schematic drawings of 6 types with 28 subgroups not any of the listed authors deals with the blood supply of the upper abdominal organs beyond a few illustrations and pages

The late Sir Arthur Keith (1866–1955) stressed the fact that in the biliary region variation is rampant For the blood supply of the supramesocolonic organs to which the author has devoted 18 years of study the phrase should be altered to read that *here variation is constant* In major features such as the celiacal and the aortic origins of the main vessels less than one half of the subjects conform to the textbook description whereas in finer details (especially terminal branching) no two arterial vascularization patterns of any of the organs *above the transverse colon* are ever the same This startling experimental fact should not bewilder the surgeon nor does it preclude the possibility of giving to him a workable familiarity with the most important and the most common with the exceptional and the rare arterial patterns with which he has to deal when operating The article of Walters and Philipps of the Mayo Clinic (1949) on the current increase of injuries to the common duct and that of Gray of London (1951) on repairs of injuries to the common bile duct should be read as a safeguard to those who think that removal of the gallbladder is a routine procedure without serious complications

Before ligating or severing an artery the conscientious surgeon should know its purpose its course and its relations Often as in gallbladder surgery the site and the size of the operative field do not permit an identification of an artery s origin It is here that the surgeon must rely on his own experiences and memory pictures and on his own incessant study of what other surgeons or anatomists have recorded When confronted by variational anatomy the surgeon should never become perturbed, for, as admirably stated by Sir William Osler In the physician or surgeon no quality takes rank *with imperturbability* the watchword of the good old Roman Aequanimitas

Pertinent here is the admonition given by the surgeon Flint, of Leeds General Infirmary England in 1923

> Technically gallbladder surgery is much the most difficult of any abdominal surgery and inadequate appreciation of the abnormalities of this region does not lessen the risk (*Brit J Surg* 10 509 1923)

*That this warning of Flint s is still appro*priate today is obvious from the plea made by the late Dr Lahey of Boston (1949)

> We should publicize the fact that cholecystectomy is a dangerous operation It is dangerous unless one realizes how important it is to control the blood supply to demonstrate definitely the anatomic relationship and to realize that anomalous anatomy is very common (*Ann Surg* 129 763 1948)

The plea of Flint and of Lahey for fuller knowledge on variational anatomy so important in surgery was presented forcefully over 100 years ago (1844) by Richard Quain Professor of Anatomy in University College and Surgeon to University College Hospital of London In his monumental immortal work *The Anatomy of the Arteries of the Human Body* (2 vols) covering a record of 1 040 bodies Quain begins his Preface with this statement

> Several years have elapsed since I became impressed with the belief that the difficulties which have often occurred in the performance of those surgical operations where the larger arteries are concerned have arisen in great part from want of sufficient acquaintance with the differences in anatomic disposition to which these vessels are subject not merely those deviations in the origin of large branches which are usually named varieties but other peculiarities

degree and the site of gut rotation (b) persistence of differently interrupted sections of the primitive roots of the omphalomesenteric (vitelline) arteries (10 11 12 13 ventral segmentals) and their longitudinal anastomoses (Tandler 1904) (c) variations in the rate and the manner of the cephalocaudad migration of the primitive gut arteries as first claimed by Mall in 1891 Factually we know only that arterial patterns vary but why they vary and to what extent is a matter for future investigators to decide

The situation of a lack of adequate knowledge regarding arterial variations and of the causes that produce them is duplicated for every major structure and organ in the human body What is needed is an encyclopedic work on human constitutional variations As previously stated only a pooling of experiences of those who for many years and on hundreds of subjects have studied a certain region or a systemic topic coupled with further extensive investigative work on regions and topics descriptively still in mere outline in texts of anatomy can bring such a work into being From present indications those now living will never see this much needed and desired encyclopedia on human constitutional variations nor is there much hope for its appearance in the future

And yet all existent constitutional variations in the anatomy of the human body are ours to know safeguard and enjoy—not to belittle neglect mutilate or destroy Their importance and application to clinical work are becoming more apparent each day in the clarification and the cause of disease in operative technic and its results and in manifold other phases of medicine and dentistry As compared with the little we now know about variational anatomy years of tedious research still lie ahead As far as research is concerned gross anatomy is not a sterile field (as is often stated by those who think that anatomy is cadaver anatomy and nothing more) but a field replete with defiant challenges to gallant and self sacrificing workers to find assemble and explain existent anatomic variations not only of the skeleton the skull and the somatotype body form but also of the soft structures amid which variations in arterial patterns are the most striking the most baffling and the most widespread

To belittle research on anatomic variations especially as observed on bodies in a dissecting room as irrelevant or as an antiquated mode of procedure when contrasted with function is inexcusable William Harvey the great physiologist and the discoverer of how blood circulates entitled his immortal work in 1628 *An Anatomical Dissertation on the Movement of the Heart and Blood* He did not call it a physiologic dissertation The new concept on the segmental division of the liver the new anatomy on the distribution of the arteries and the bile ducts in the human liver as worked out in plastic casts by Healey and Schroy at the Daniel Baugh Institute of Anatomy together with the present contribution are striking examples of what still can be done with the anatomy of a corpse

New surgical procedures are often based on a fuller understanding of the underlying anatomy as instanced in modern bronchopulmonary resection in the intrapericardial approach to pulmonary vessels for removal of a lung in an intracardiac approach to rectify congenital and acquired heart defects and in resection and exenteration of pelvic and abdominal organs not to mention the tremendous progress that has been made in the detection of brain tumors via a study of injected blood vessels and the progress that is being made in roentgenography in the diagnosis of diseases by arteriograms and the now prevalently

Finally as a time saving device to the busy surgeon an atlas with numerous illustrations is effective because the knowledge which he needs in the operating room can be gained more readily and more accurately from a careful study of an adequate number of well selected illustrations than by reading intricate and extensive texts or by relying on percentage variations alone

To select the most common patterns of blood supply and to supplement these with simple schematic drawings showing deviations of an arbitrarily established standard is a commendable procedure for introductory purposes such as the instruction of first year students in anatomy but certainly such a method should not be adopted in the preparation of an atlas intended primarily for surgeons and the main aim of which is to be as comprehensive and as instructive as possible In the illustrations given in this atlas it is to be expected that there will be repetitions for many arteries remain unaltered In view of existent variational anatomy the samples presented are certainly neither too copious nor too bewildering even to the surgeon pressed for time Once the mode of branching and the origin of the regional blood vessels are understood (in which the accompanying text will give aid) the reader need not study each illustration in detail for the salient variation of each case will come immediately to his notice this being the essential aim and purpose of the atlas

Today in all fields of medicine it is a well recognized fact that constitutional anatomy is a constant variant but the authors of such a text on variational anatomy are still eagerly awaited—the task of compiling such a work is far too great for one man to undertake Only a pooling of experiences and further prolonged investigative work on variations can solve one of the greatest problems that confronts modern medicine—man as he really is developmentally and therefore constitutionally different in each case this as regards all the anatomically delineated systems (skeletal muscular nervous cardiovascular lymphatic urogenital and digestive systems) and as regards the structure of the organs of special sense (eye ear nose)

Despite 400 years of anatomy there is today not one scientific work which accounts for this diversity of arterial patterns extant in human bodies whether of the celiac axis the axillary artery the thyrocervical trunk the hypogastric artery or the circle of Willis Speculatively considered the causative factors for arterial variations may be (1) *Variations in constitutional inheritance,* of which we know practically nothing anatomically speaking for the body of the father or the mother of the body studied is never dissected This problem can be worked out only in animals (2) *Variations of evolution,* i e atavistic remnants of either a progressive or a regressive nature This is another impossible route for the human species because of lack of material (3) *Variations in hemodynamic potential,* the type and the intensity of activity of a given organ and its rate of growth determining the constitution and the distribution of the arterial pattern (Thoma Mall) (4) *Variations of race difference,* in the sense that the anatomy we know and teach including arterial arrangement is purely European whereas race differences fully comparable with those extant in osteology and somatology actually exist in all soft structures as claimed and indicated by the findings of Adachi (1928) of arterial variations in the Japanese (5) *Ontogenetic developmental peculiarities* the patterns of the arteries being determined by internal and external factors

For the arteries to the suprameso colonic organs (celiac superior mesenteric) developmental peculiarities would be correlated with (a) variations in the

degree and the site of gut rotation (b) persistence of differently interrupted sections of the primitive roots of the omphalomesenteric (vitelline) arteries (10 11 12 13 ventral segmentals) and their longitudinal anastomoses (Tandler 1904) (c) variations in the rate and the manner of the cephalocaudad migration of the primitive gut arteries as first claimed by Mall in 1891 Factually we know only that arterial patterns vary but why they vary and to what extent is a matter for future investigators to decide

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used cholangiograms Despite the fact that in recent years the teaching of anatomy has been curtailed severely in the medical curriculum of many schools today as initially at every forward step of medicine the adage of the old masters still holds Anatomia est oculus medicinae That men differ in mode of thinking was curtly expressed long ago in the Latin proverb Quot homines tot sententiae For existent constitutional differences the proverb may well read Quot homines tot anatomiae

Because of anatomic variations surgical injuries in the living body can inadvertently and readily be made by even the most experienced surgeon Often such injuries (for example stricture of the common bile duct due to clamping of blood vessels) can be repaired with adequate technic and care All too frequently however surgical injuries especially to sustaining blood vessels are irreparable as attested by the fatal necrosis of the part involved It was for this reason that Halsted pioneer American surgeon spent years in a serious and vigorous campaign educating prospective surgeons to keep abreast with anatomy and in particular to have a healthy respect for life sustaining arteries when operating Halsted will be remembered not only for having made possible the extension of antiseptic operative surgery by the introduction of rubber gloves (1890) but also everlastingly he will be remembered for the message he left to surgeons that the best way to avoid injury to blood vessels is to know them and to know how when and where to ligate them properly

Errors in surgery will always be made for the surgeon is but human However a record of surgical failures in any community or hospital is a calamity and is unquestionably the sequel of the fallacy of supposing that good surgery can be performed without adequate preparation under reputable experienced surgeons and without knowledge of the regional anatomy and its pertinent blood supply An obvious lack of interest on the part of the surgeon in arterial arrangements, an indifference in his mode of handling blood vessels sooner or later, will result during the course of his operative procedures in disconcerting postoperative complications for which he was largely responsible Key facts regarding the variability in the origin and the distribution of arteries can be abstracted and learned for, as in all phases of human effort and accomplishment, we learn what we need to learn

Responsibility for teaching arterial variations lies with the anatomist action in their mode of severance is the problem of the surgeon Anatomy and surgery are forever intertwined An anatomist need not be a surgeon and today rarely is but a surgeon must always know in particular and in detail the anatomy of the body region he has selected for his operative procedures In speaking on the responsibilities of the surgeon one of America's greatest pioneer surgeons Samuel D Cross (1805–81) a graduate (1828) of and the fourth Professor of Surgery of the Jefferson Medical College made this everlastingly true statement What other profession or pursuit is there that involves so much mental anguish so much awful responsibility so much wear and tear of mind and body?

If with this atlas and text the author succeeds in lessening the degree of worry and the instances of injury during surgical operations—if by the knowledge presented human lives will be saved—then the 18 years spent in assembling the facts of arterial variations depicted and described in this atlas will be well repaid

By a strange coincidence the experience of the author regarding arterial variations is comparable with that experienced by Tiedemann Professor of Anatomy and Physiology at the Univer

sity of Heidelberg In his large atlas of 18 lithographic plates on the arteries of the human body written in Latin and in German and published in Karlsruhe in 1822 he makes the following statement in his Preface

Um wo moglich eine recht genaue und gründliche Kenntniss der Pulsadern zu erlangen habe ich seit sechszehn Jahren die grosste Aufmerksamkeit auf den Ursprung und Verlauf derselben gerichtet mehr denn funfhundert menscichse Korper beiderlei Geschlectes und aller Alter habe ich zu diesem Behuf zerkliedert Wie veil Muhe auf diese Arbeit verwendet wurde dass konnen nur diejenigen beurtheilen welche dieses Werk mit einigem Nachdenken betrachten werden Sicherlich hatte ich eine mit so vieler Anstrengung and Zeitaufwand verbundene Arbeit nicht unternommen wenn ich nicht die Hoffnung gehegt hatte sie wurde bei der Ausubung der Heilkunde einigen Nutzen gewahren

In the English edition of Tiedemann s work translated by Knox the cited lines read

That I might if possible render my knowledge of the arteries fuller and more accurate than any one s I have laboured with indefatigible zeal for sixteen years in investigating their origin and distribution I have with my own hands dissected upward of five hundred bodies and examined with no small degree of diligence subjects of both sexes and of all ages How much time and labor this task necessarily required those alone who have witnessed and properly considered this type of work can be adequate judges Indeed I by no means would have engaged in an undertaking so arduous and linked with so many difficulties had I not been cheered by the advantage that would from thence accrue to medical science

Wholesome truths and experiences because of conventional frozen modesty are often relegated to oblivion When the author received his doctorate degree (D Sc) from the University of Louvain in Belgium (1922) as a pupil of the eminent cytologist Dr Victor Gregoire little did he then surmise or foresee that 33 years later he would publish an atlas on the varied blood supply of the upper abdominal organs the need for such a work on the celiac axis having been emphasized by Haller in his *Icones* in 1756 It was during the time that he was a student at Louvain University (1528–33) that Vesalius made his first anatomic dissections of small animals and after his return from the University of Paris (1536–37) reconstructed the first skeleton from a dried cadaver of an executed individual His epoch making book *De humani corporis fabrica* dedicated to Charles V and on which he worked for 4 years and which marked the beginning of modern anatomy was published in June 1543 in Basel Switzerland Although but 28 years old when he published his *Fabrica* Vesalius was fully aware of the paramount importance of anatomic knowledge for an understanding of surgical lesions regarding which in his Preface he wrote these everlastingly true words In whose cure we behold the appointed place of the true and highest power of medicine

I find the great thing is not so much where we stand as in what direction we are moving. To reach the port of heaven we must sail sometimes with the wind and sometimes against it, but we must sail and not drift nor lie at anchor.

—OLIVER WENDELL HOLMES

2

Review of the Literature

The literature on the blood supply of the upper abdominal organs is restricted preponderantly to specific organs or to generalized types of the celiac axis. Relatively few authors have investigated and depicted the topographic relations of the entire arterial pattern emanating from the celiac axis and the upper segment of the superior mesenteric artery. No one has undertaken the arduous task of dissecting from origin to distribution all of the major arteries to the liver, the gallbladder, the stomach, the duodenum, the pancreas, and the spleen in so large a sample as the present study (200 bodies). Since the publication of the author's article on the splenic artery (1912) from time to time he has published his observations on the blood supply of the upper abdominal organs only in abstract form. The reason for this unusual procedure was that a fairly complete picture of existent anatomic arrangements was desired before making an attempt at generalizations and estimates and a reduction of observed arterial patterns to definite types which could readily be visualized and remembered. Since the primary purpose of this atlas is to afford the surgeon a readily accessible pictorial record of the varied blood supply of the mesocolonic organs, the literature on the regional arteries will be discussed very briefly and only insofar as it will help to orientate, clarify and substantiate the factual observations presented.

Pedro Belou, for many years Professor of Anatomy at the University of Buenos Aires, Argentina, published a large monograph in 1915 which in this country and elsewhere was largely inaccessible and overlooked, having been written in Spanish, but which will always be regarded among anatomists as one of the greatest pioneer investigations on the variational anatomy of the cystic artery and the biliary ducts. His monograph, *Anatomia de los conductos biliares y de la arteria cistica*, comprises 302 pages and contains 102 illustrations, 9 colored plates of structures seen through the hepatogastroduodenal omentum, and 7 pages of literary references up to the year 1915.

Belou's work is based on a dissection of previously injected arteries made *in situ* in 80 adult bodies (freshly preserved), 35 fetuses and 10 different vertebrates. Location and course of the biliary ducts as ascertained by cross sections are depicted. Topics discussed and investigated by Belou comprise the derivation of the cystic artery, the relations of the biliary ducts to the cystic and the hepatic arteries, the mode of formation of the hepatic duct and the modalities of its union with the cystic duct, the relations of the four segments of the choledochus, the mode of orifices of the bile and the

pancreatic ducts in the duodenum, the gastroduodenal artery, the posterior pancreaticoduodenal arcades, and the comparative anatomy of the bile ducts from fish to man.

Belou resuscitated interest in the surface projection of the biliary tract on the anterior abdominal wall made possible through the triangle of Chauffard (angular zone bounded to the left by the syphopubic line and to the right by a transverse line drawn from the umbilicus. A line bisecting the angle will pass through the second part of the duodenum at the ampulla of Vater). In addition to discussing the cystic triangle of Calot, which he modified, Belou gives the boundaries of a new triangle termed the interportocholedochal triangle. Located between the portal vein and the choledochus, it is a helpful one, for it may contain an ascending right hepatic derived from the superior mesenteric or an ascending right hepatic that passed behind the portal vein after its origin from the celiac.

An excellent view of the literature on constituents of the hepatic pedicle (normal and aberrant hepatic arteries, cystic artery and biliary ducts) is that prepared by Thompson of Canada (1933). In this classical monograph, published by the University of California Press, the statistical data from the literature contributed by 17 authors up to 1933, together with Thompson's observations on 50 bodies, are placed in distinct categories where they are compared and combined on the basis of observed and theoretical frequency. Thompson's 50 sketches on the arteries and the ducts of the hepatic pedicle are excellent demonstrations of the variations that may be encountered in the biliary region. In the 50 specimens he investigated, aberrant hepatic arteries occurred in 28 per cent, dual cystic arteries in 18 per cent.

As early as 1900, Brewer, under Huntington at Columbia, called attention to the frequency of anomalies in the hepatic pedicle by stating that "in 50 dissections only 3 cases conformed to the textbook description of arterial arrangement," and his 50 illustrations confirm the statement. Budde (1906) emphasized the frequency of a right hepatic from the superior mesenteric coursing in the cystic triangle, which, because of this warning, is sometimes called the triangle of Budde.

Hunt of Leeds, England, at the request of the surgeon Sir Berkeley Moynihan, in 1923 made dissections of the biliary region in 200 postmortem subjects and noted that the textbook arrangement of vessels and ducts occurred in only 69 of the 200 bodies and that 31 (15.5 per cent) had accessory cystic arteries. From this he concluded that "so frequent are variations that it is impossible to regard any one type as normal."

Browne of Tulane University (1940) found the cystic artery to be normal in 153 of 280 specimens (54.7 per cent). Fifty-eight bodies (20.7 per cent) had 1 and 8 bodies had 2 accessory cystic arteries. Browne stressed the fact that "double or multiple vessels were found in this series in practically 1 out of every 3 cases."

The work of Daseler, Anson, Hambly and Reimann is the most recent (1947) to substantiate the remarkable frequency of arterial variations (especially of the cystic artery) in the hepatic pedicle. These authors gave a statistical report of their investigations of 500 specimens obtained chiefly from the anatomic laboratories of Northwestern University. They selected for publication 66 small schematic sketches of variations of the celiac axis, 12 sketches of the types of cystic artery distinguished and 11 small drawings on constituents of the hepatic pedicle. Later on in this book their percentage values on aberrant hepatic arteries and on types of cystic arteries will be

compared with those of the present author

From Northwestern University Johnston and Anson 5 years later (1952) published observations made on 35 bodies regarding the relationships of hepatic ducts to accompanying hepatic arteries especially in the intrahilar area In addition to their own observations and surgical considerations the cited authors gave a comprehensive literary review of the findings of previous investigators It is interesting to note that in their own specimens the typical textbook pattern of a cystic artery arising from the right hepatic in Calot s triangle occurred in only 40 per cent that dual cystic arteries were present in 17 per cent and that accessory hepatic ducts occurred with a high incidence of 31 per cent

The first extensive description of the celiac artery was given by Haller (1756) in his large work on arteries As previously stated he deplored the fact that there was no atlas depicting existent variations of the artery While he made no attempt to classify the types of celiac artery encountered he recorded some of the most outstanding variations—viz that the celiac may be derived from the superior mesenteric that it may give rise only to the splenic and the left gastric the hepatic arising from the superior mesenteric that the left gastric may be derived from the splenic that the left gastric may arise from the aorta above the celiac that the left gastric may give a large branch to the liver and therefore such arteries should be known as *gastrohepaticae sinistrae* that the pancreaticoduodenal artery before it descends behind the pylorus may give off a small hepatic to the umbilical fossa and that it gives off a branch which supplies the back of the pancreas (undoubtedly the retroduodenal artery)

To illustrate his description Haller gives 3 plates (a) one with the stomach lifted up showing the celiac axis and the superior mesenteric (b) a view of the gall bladder (c) an *in situ* view of the celiac Because of his work the celiac artery has long been known as the tripod of Haller But Haller was not the first to describe the artery as dividing into 3 branches for he states

> Truncus coeliacae saepe tripes sit in coronarium splenicam et hepaticam fecta ut primus Lowerus descripsit tum Winslow Verdier Lieutand et videtur pingere Cowperus Vidit etiam Walherus et ego frequenter

Tiedemann (1822) of the University of Heidelberg in his large work on arteries gives 2 plates on the celiac artery Plate 21 depicts a celiac axis in which the hepatic divides into 3 branches (right left and middle) the latter entering the quadrate lobe In Plate 22 the stomach is lifted up to show the course of the splenic and the left gastro epiploic Tiedemann states that the hepatic occasionally arises from the aorta that it may be a branch of the superior mesenteric and that the left hepatic often arises from the left gastric Hepatic arteries may be multiple one arising *in situ* the other from the left gastric or the superior mesenteric Under the term ramulus ad pylorum Tiedemann depicts a branch which courses to the first part of the duodenum and is undoubtedly the supraduodenal artery of Wilkie

The monograph of Adachi (1928) is the most comprehensive and the most extensively illustrated insofar as the variational anatomy of the celiac axis itself is concerned As Professor of Anatomy at the Universities of Okayama and Kyoto Adachi spent 30 years studying arterial and venous variations in 252 Japanese His monumental work of two volumes with 539 illustrations is written in German and contains a thorough review of the literature from which the observations the terminology and the percentages recorded by previous investi

gators on arterial and venous variations of the entire body are categorized and compared with his own

In dealing with the celiac axis Adachi emphasized the fact that any classification of celiac types is purely arbitrary as there are many doubtful cases as to which group they belong As a basis for his typing of celiac axis he used the disposition of 4 arteries (left gastric hepatic lienal and superior mesenteric) and for his grouping took into consideration 6 additional arteries (accessory left gastric accessory left hepatic intermediate forms of these accessory right hepatic from the celiac trunk or superior mesenteric and gastroduodenal) hence a total of 10 arteries With an arbitrary concept as to what constitutes a true and an accessory right hepatic (the former running anterior the latter posterior to the portal vein) Adachi distinguished 6 types of celiac axis the types comprising a total of 28 groups In view of the relative inaccessibility of Adachi s work his classification of the celiac axis may be summarized briefly as follows

Type I—The left gastric the lienal and the hepatic arise from a common trunk (hepatogastrolienal) 87 7 per cent (11 groups) *Type II*—The left gastric is a direct branch of the aorta the hepatic and the lienal form a common trunk (hepatolienal) 6 3 per cent (6 groups) *Type III*—The left gastric is a direct branch of the aorta the hepatic the lienal and the superior mesenteric form a common trunk (hepatolienomesenteric) 1 2 per cent (2 groups) *Type IV*—The left gastric the lienal the hepatic and the superior mesenteric form a common trunk (celiacomesenteric) 2 4 per cent (3 groups) *Type V*—The left gastric and the lienal form a common trunk (gastrolienal) as a direct branch of the aorta The hepatic and the superior mesenteric arise from a common trunk (hepatomesenteric) 0 4 per cent (1 case) *Type VI*—The left gastric and the lienal form a common trunk (gastrolienal) from the aorta the hepatic artery is missing The liver is supplied by an accessory right or left hepatic or by both 2 per cent (5 groups)

In Adachi s sample of 252 bodies accessory left hepatics arose from the left gastric in 17 9 per cent accessory right hepatics were derived from the superior mesenteric in 10 3 per cent and from the celiac trunk in 2 per cent The hepatic was never encountered as a direct branch of the aorta although Rossi and Cova (1904) observed 4 cases in 102 bodies Lipshutz (1917) 3 in 83 and Eaton (1917) 1 in 206 Adachi described the middle hepatic (ramus medius) as a distinct branch of the hepatic (from the right hepatic 50 per cent from the left hepatic 40 per cent) and regarded it as the specific artery for the quadrate lobe No account was taken in his work of the celiacal dorsal pancreatic artery or of the superior and the inferior pancreaticoduodenals Little was reported regarding the cystic artery while the terminal divisional patterns of the hepatic and the splenic were not considered at all

Previous to the author s first studies on the subject (1942) variations of the celiac axis and the hepatic and the cystic arteries had been investigated in the Daniel Baugh Institute of Anatomy of the Jefferson Medical College by the anatomist Eaton and by the surgeons Lipshutz and Behrend In a pioneer work published in 1917 Lipshutz is one of the few investigators who illustrated observed celiac types with 4 full regional drawings of topographic relations In an examination of 83 bodies he distinguished 4 types of celiac axis (1) common trunk for left gastric splenic and hepatic (75 per cent) (2) common trunk for hepatic and splenic left gastric from aorta (15 per cent) (3) common trunk for hepatic and left gastric splenic from aorta (6 per cent) (4) common trunk

for left gastric and splenic hepatic from aorta (4 per cent) In 35 per cent an accessory hepatic arose from the left gastric in 15 per cent from the superior mesenteric In 3 cases the cystic took origin directly from the superior mesenteric Two celiacomesenteric trunks were noted

Faton of Johns Hopkins University (1917) classified the 206 celiac axes he studied (40 from the anatomic laboratories of the Jefferson Medical College) into 5 types and 4 classes (15 illustrations) *Type I*—Left gastric and splenic form a common trunk the hepatic from the aorta or the superior mesenteric *Type II*—Tripod celiac with classes showing accessory hepatics and a pancreatic branch *Type III*—Common trunk having the left gastric as its first branch with classes showing accessory hepatics and a pancreatic branch *Type IV*—Left gastric as a separate branch from the aorta the hepatic and the splenic forming a common trunk which may have a pancreatic branch In 7 per cent of the cases the left gastric gave off an accessory hepatic From data in the literature Faton calculated that the classical tripod of Haller occurred in 24 per cent of 541 cases He listed the dorsal pancreatic as a distinct branch of the celiac and gave 6 illustrations of it An unusual celiacomesenteric trunk was reported by Munger of Tulane University (1941)

The observations of Behrend on variations and dispositions of hepatic and cystic arteries and biliary ducts (made over a period of years in the anatomic laboratories of the Jefferson Medical College) were described and illustrated with a large series of drawings of the hepatic pedicle in book form in 1927 Many of the drawings illustrate the peritoneal bands passing from the gallbladder to the stomach the duodenum and the transverse colon In interpreting them the view is taken that they are not inflammatory adhesions For the new edition of this work (1947) the present author contributed 12 sketches and 1 colored drawing showing characteristic types of the blood supply to liver gall bladder stomach, duodenum and pancreas

Leaving the hepatic pedicle and the celiac axis a few remarks are pertinent regarding some of the most recent investigations on the blood supply of the upper abdominal organs As regards the blood supply of the pancreas it is indeed lamentable that few texts on anatomy or surgery present an adequate description or illustration of the blood supply of this important organ the nearest approach to accuracy being that given in the eleventh edition of the Schaeffer Morris *Human Anatomy* (1953) and in Grant s *Atlas of Human Anatomy* Major surgery of the pancreas is relatively recent it having been avoided largely because of the fear of hemorrhage (Berg 1948) that practiced prior to 1919 is described by Sir Berkeley Moynihan in Keen s *Surgery* (vol 3)

Numerous investigators have contributed to our knowledge of the blood supply of the pancreas this from the time of Vesalius (1564) through the time of Winslow (1732) Haller (1748) Bell (1797) Verneuil (1851) Testut (1893) Wiart (1899) down to the present as instanced by the works of Rio Branco (1912) Belou (1915) Romodanowskaja (1926) Petren (1929) Wharton (1932) Edwards (1941) Wilmer (1941) Michels (1942) Ziegler (1942) Pierson (1943) Falconer and Griffiths (1950) Woodburne and Olsen (1951) and Bertocchi (1953)

That the duodenum and the head of the pancreas are supplied by two arterial arcades one anterior and the other posterior was first accurately described by Haller in 1756 In his chapter on the celiac he states that the pancreaticoduodenal artery (i e the gastroduodenal) always gives off a branch (duodenam

superiorem dextram) which courses to the right crosses the common bile duct and after supplying the duodenum and the pancreas posteriorly unites with a branch of the superior mesenteric From further reading it is clear that the artery described is the retroduodenal

Subsequent authors failed to mention this retroduodenal artery despite the fact that in 1899 Wyatt again restated the view of Haller—viz that the gastroduodenal always gives off a large collateral branch (artère pancréatico duodénale supérieure droite) which forms the upper limb of the arterial arcade behind the head of the pancreas The anatomic atlas of Bourgery published in 1839 contains the earliest illustration of the two arcades made by the superior and the inferior pancreaticoduodenal arteries An accurate and beautiful lithographic colored drawing of the retroduodenal artery as it crosses the supraduodenal portion of the common bile duct is likewise given by Quain (1844 plate 15 vol I) He does not label the artery as such but merely states that it is a branch to the duodenum In vol II plate 19 he presents a colored drawing showing the first part of the duodenum as having two supraduodenal arteries (of Wilkie) one from the hepatic the other from the right hepatic (again not labeled as such) Regarding the cystic artery Quain states that it divides into two branches (two ramusculi of which one ramifies between its coats at its depending surface the other between it and the liver) Plate 50 vol II shows a beautiful lithographic illustration of the blood supply of the upper abdominal organs

Of modern texts on gross anatomy Testut gives a colored drawing (Fig 370) of the anterior and the posterior pancreaticoduodenal arcades (anses) and in Figure 158 depicts the peripancreatic arterial circle about the pancreas Poirier and Charpy in their anatomic text give an accurate description and illustration (Fig 158) of the ventral and the dorsal arterial and venous arcades found about the duodenum and the head of the pancreas (vol IV Part I 1912)

Pedro Belou of the University of Buenos Aires, Argentina (1915) in his classical monograph gave a lengthy and accurate description of the posterior pancreaticoduodenal arterial and venous arcades *and illustrated two of the variational* types most commonly encountered The posterior arcade is made by the pancreaticoduodenal posterosuperior (the author s retroduodenal) and was found to be a branch of the gastroduodenal in 97 per cent and of the pancreaticoduodenal anterior superior in 3 per cent According to Belou, the posterior pancreaticoduodenal arcade may be precholedochal or retrocholedochal above and retrocoledochal below

Petren of Sweden (1929) examined the pancreaticoduodenal arcades in 42 cases at the Anat Karolinischen Inst Stockholm and has given us the best and the most accurate description and illustration of them Usually 2 occasionally 3 seldom 4 in number the arcades arose from the gastroduodenal the anterior from an end branch of this vessel (sup pancreaticoduodenalis anterior) the posterior from a collateral branch of the same vessel (sup pancreaticoduodenalis posterior) In most instances the arcades united with one another before ending in the superior mesenteric via a common inferior pancreaticoduodenal

Wharton of the Mayo Foundation (1932) studied the blood supply of the pancreas in specimens injected with Berlin blue in 25 gross dissections and in 10 casts made by the celluloid corrosion method Of the main vessels he noted the inferior pancreatic artery coursing along the inferior surface of the pancreas The intrapancreatic circulation (to which the major part of the paper is devoted) consists of interlobular and intralobular arteries and veins A single

artery enters each lobule where it ends in a glomerulirlike structure among the islands of Langerhans.

Wilmer of the University of Minnesota (1911) gave a detailed description of the gastroduodenal plexus on the posterior wall of the duodenum as ascertained in 7 subjects (6 newborn) with a celluloid corrosion injection method. He noted that the pattern of the pancreaticoduodenal arcades and their anastomoses varied in each case. Typically there are 2 superior and 2 inferior pancreaticoduodenal arteries. These are united across the posterior wall of the duodenum in so many places (6 to 12) that ligation of any of the plexus vessels to control bleeding in massive hemorrhage from an ulcer on the posterior wall of the duodenum is deemed futile.

Ziegler of the University of Rochester (1912), with the co-operation of Drs. Hawkins and Mason, noted that in 12 out of 21 dissections the inferior pancreaticoduodenal had a high origin from the superior mesenteric instead of a low one, as usually described in texts of anatomy. Ligation of a high inferior pancreaticoduodenal, in his opinion, would seriously endanger the vitality of the third part of the duodenum supplied in fan-shaped manner by this artery.

The observations of Pierson of the University of Oregon (1943) on the arterial blood supply of the pancreas are based on 50 dissections. In addition to his own two accurate illustrations he published 3 illustrations as modified from Petren and 1 as modified from Rio Branco. The pancreatic vessels comprised (1) the anterior and the posterior duodenal arcades, (2) the superior pancreatic, which passes dorsal to the neck of the pancreas, and (3) the inferior pancreatic, embedded in the dorsal surface of the pancreas and coursing from right to left to unite with branches of the splenic. In a short note on the retroduodenal artery Pierson follows the concept of Wilkie. Woodburne and Olsen of the University of Michigan (1951) investigated the arteries of the pancreas in 150 specimens. In addition to confirming the constancy of the anterior and the posterior pancreaticoduodenal arcades, they obtained percentages as to the incidence of the dorsal pancreatic (90 per cent), of the inferior pancreatic (i.e., transverse pancreatic, it being constant), of the pancreatica magna artery (61.7 per cent) and of caudal pancreatic arteries (78.7 per cent). Sites of origin of these respective arteries were also reported. Bertocchi, of the University of Torino, Italy (1953), in an anatomicoradiographic study of 12 bodies distinguishes a superior and an inferior pancreaticoduodenal arcade. The superior arcade is made by the right superior pancreaticoduodenal (the term he used for the retroduodenal) which arises from the posterior surface of the gastroduodenal and unites with the superior mesenteric. The inferior arcade is made by the right inferior pancreaticoduodenal, a terminal branch of the gastroduodenal, the other terminal being the right gastroepiploic.

That the first part of the duodenum has its own and independent blood supply was first claimed by Wilkie of Edinburgh (1911). In a study of 10 subjects he noted that when he injected the gastroduodenal with a starch vermilion solution, the colored material traveled freely into the second, the third and the fourth parts of the duodenum but failed to reach the upper half of the first 1½ to 2 inches of the duodenum. When he tied off the left gastric, the splenic, the right gastric and the gastroduodenal, the injected material reached the upper two thirds of the anterior wall and the upper one third of the posterior wall of the first part of the duodenum. Since the artery that supplied this critical area descended on the duodenum from a trunk which had its origin at a

higher level than the midpoint of the gastroduodenal artery he named it the supraduodenal artery The supraduodenal artery is not to be confused with another artery which Wilkie named the retroduodenal Of this he said

In the majority of cases a second artery was found springing from the gastroduodenal about half an inch above its bifurcation and supplying the posterior wall of the first part of the duodenum and sometimes reaching to its second part This vessel though not constant was generally present and I have ventured to name it the retroduodenal artery (*Surg Gynec & Obstet* 13 399 1911)

Wilkie found the supraduodenal artery to have a varied origin from the gastroduodenal (22 cases) the right hepatic (7) the left gastric (6) the common hepatic (2) as a branch of the right gastric (1) from the cystic (1) In 2 cases it was represented by 2 vessels. Since in the majority of cases the supraduodenal did not anastomose with any other gastric or duodenal artery Wilkie thought it to be an end artery In conformity with the observation that the first one half to three fourths of an inch of the upper border of the duodenum (especially on its posterior aspect) has a relatively poor blood supply this fact induced him to state that the tendency of ulcers to perforate on the upper border of the duodenum just beyond the pylorus is due to the paucity of a blood vascular supply

The critical area on the first part of the duodenum of which Wilkie speaks was known to William J Mayo of the Mayo Clinic for in 1908 he called attention to the fact that when the pylorus and the first part of the duodenum were pulled down at operation an anemic spot appeared on the anterior wall of the duodenum According to Wilkie stretching of the supraduodenal artery distributed to this area is the factor producing the pallor

Reeves of Minnesota University (1926) found the arrangement of arteries along the lesser curvature and through the first part of the duodenum to be such as to predispose them to thrombosis thus substantiating Wilkie s contention that a regional vascular insufficiency is a causative factor in chronic ulceration According to his observations the first 1½ inches of the duodenum is supplied by the supraduodenal artery Its main branch reaches the anterior surface where it anastomoses rather sparingly with the branches of the right gastric the right gastro epiploic and the superior pancreaticoduodenal In studying the plexus of vessels in the submucosa of the lesser curvature Reeves noted that the arteries were smaller longer and less frequently anastomosed than in other regions of the stomach whereas in the first part of the duodenum the arteries composing the submucous plexus were of the gastric type—they were small relatively few and not so freely anastomosed as compared with other parts of the duodenum

Edwards of the University of Ohio (1941) in an investigation of 100 bodies noted that in nearly every instance (97 per cent) the posterior surface of the duodenum had an artery (a branch of the gastroduodenal) which he termed the retroduodenal In adopting this term Edwards extended the vascular area supplied by the retroduodenal to the entire posterior duodenal wall for originally Wilkie had restricted its specific area of vascularization to the first and the second parts

Falconer and Griffiths of Edinburgh (1905) examined the blood vessels in the region of the pancreas in 50 specimens (27 dissections 23 injected specimens) Arterial arrangement was found to be essentially the same as that reported by Petren Their account on the veins of the pancreas is an important addition to the literature and should be

referred to by those interested in the venous drainage of the pancreas For the venous drainage of the gallbladder the reader is referred to the excellent doctorate thesis work of Petren of Stockholm (1933) it being a phylogenetic study from fish to man

In the author's article on the spleen and the splenic artery (1942 Fig 30) a typical illustration of the retroduodenal artery, as the first branch of the gastroduodenal was given While the blood supply of the pancreas was not discussed as such many of the author's drawings of the pancreas show the topographic relations of the dorsal pancreatic (superior pancreatic of Petren and Pierson) its varied origin from the first part of the splenic the hepatic or the celiac its varied and frequent anastomosis with neighboring vessels The same drawings illustrate samples of the origin the course and the distribution of the transverse pancreatic artery of Haller (the inferior pancreatic of Testut Petren Pierson Woodburne and Olsen) In many instances the artery is shown as the left branch of the dorsal pancreatic coursing leftward along the inferior surface of the pancreas toward the tail of which it anastomoses with a terminal branch (a caudae pancreatis) of the splenic The posterior epiploic branches from the transverse pancreatic to the transverse mesocolon are likewise illustrated In one instance a transverse pancreatic arising from the superior mesenteric was sufficiently large to constitute an a splenica secunda as shown in the same article in Figure 21 (See Fig 121)

Regarding the blood supply of the stomach Arnold (1847) was one of the first to give an accurate description of its vessels Disse (1904) introduced the concept that the mucosal arteries were end arteries a view categorically disproved by Djorup (1922) and more recently by Barlow Bentley and Walder (1951) Although Jatrou (1920) Reeves (1920) Hoffman and Nather (1921) and others gave extensive analysis of the anastomosing vessels of the stomach the true nature of the minute distribution of the blood vessels in the anterior and the posterior stomach wall was first ascertained definitely in the recent work of Barlow Bentley and Walder from the University of Durham (1951)

Using postmortem specimens these authors injected the arteries with 20 per cent chlorbismol at a pressure of 130 mm Hg The capillaries were investigated by injections of a 10 per cent colloid silver iodide solution after the specimens were fixed microradiographs of frozen sections were made These authors concluded that the arrangement of the vessels in the mucosa is the same in all parts of the stomach the mucosa of the lesser curvature being no exception for on the basis of vascular patterns a section of it could not be distinguished from any other part of the stomach The capillaries of the mucosa are supplied by long mucosal arteries about 120μ in diameter which obliquely cross the submucosa and penetrate the muscularis mucosae to reach the glandular layer In the anterior and the posterior walls of the stomach the mucosal arteries arise from an extensive plexus of large vessels in the submucosa which in turn is supplied by branches from the arterial chain along the greater and the lesser curvature Mucosal arteries break up into 3 to 4 branches that twist and coil upon each other before piercing the muscularis mucosae About 90 to 120 of these branches perforate each square centimeter of the muscularis mucosae On the glandular aspect of the latter the branches anastomose freely forming a network from which the mucous membrane is supplied

In the pyloric antrum the submucous plexus consists of smaller vessels In the region of the lesser curvature there is no submucous plexus the small com

municating channels seen here are but fine anastomosing branches which connect mucosal arteries in all parts of the stomach. Decidedly interesting is their *observation that, in the region of the* lesser curvature, the mucosal arteries do not arise from a plexus of vessels within the stomach wall, but have their origin outside the stomach—i.e., they arise directly from the right and the left gastric arterial chains. Throughout the stomach there is a wide connection of the mucosal arteries by their free anastomoses as they approach the *muscularis mucosae* and again on the glandular aspect of this muscle.

Anatomically considered, *there are no end arteries*, the freely anastomotic character of the vessels of the stomach being its most noted feature. Numerous channels exist whereby large quantities of blood may be brought to the mucosa or transferred from one region of the stomach to the other. This shifting of blood in the stomach wall is facilitated by numerous direct arteriovenous channels measuring up to 110μ in diameter and characterized by having a musculo-epithelial type of cell, as shown by Clara. At point of junction these sinuous arteriovenous channels become narrowed, but elsewhere they have a diameter of 30μ. They afford an excellent mechanism of short-circuiting the mucosal arterial blood flow directly into the veins.

In perfusion experiments these authors showed that large or small glass spheres (40μ to 140μ) when introduced into the arterial flow could be recovered in the venous outflow. Depending on conditions, the shunts remain open or shut. When the rate of flow through the stomach vessels was reduced, there was an increased flow through the shunts, and, conversely, conditions which increased the rate of flow through the stomach vessels caused a decreased flow through the arteriovenous anastomoses. The authors refer to the previous work of Barclay and Bentley (1949) in which the presence of functioning arteriovenous shunts in the stomach was demonstrated by changes of oxygen saturation *in the venous blood* and by *micro-arteriography*, and to the work of de Busscher (1948) who demonstrated arteriovenous anastomoses in the mucous and the submucous layers by means of reconstructions of serial sections.

The literature on the splenic artery and its ramifications in the spleen is far too extensive to be reviewed adequately *in this short survey*. *Data on the intra*splenic circulation may be found in the standard reference works of Krumbhaar (1926), Hartmann (1930), McNee (1931), Keyes (1932), Barcroft (1936), Klemperer (1938) and Bjorkman (1947). For this atlas a reference to major contributions on the splenic artery will be sufficient.

Julius Caesar Arantius of Vienna *(1751) frequently is regarded as the* "discoverer" of the splenic artery, having been the first to emphasize its tortuous course ("arteriae lienis ductum obliquum ac flexuosum anguis in modum primus observavit" ... ita Doughlas 1754, cit. Henschen 1928). The phenomenon of the tortuosity of the splenic artery was known to the artist Leonardo da Vinci in the sixteenth century, for he made mention of the fact that in old people the splenic artery increases in thickness, grows longer, then becomes twisted like a snake. Henschen's classical monograph, prepared at the University of Basel, Switzerland, in 1928, contains numerous references to the literature, one to the effect that an a. splenica secunda was described by Haller in 1764:

> Aliquando sed raro secundus truncus minor a coeliaca ad splenem venit prius ex coeliaca natus quam splenicus vulgaris.

Among the older anatomists who have contributed to our knowledge of the splenic artery may be listed Sylvius (1614–72), Columbus, Winslow (1669–

1760) Jessenius A v Haller (1708–77) Luschka (1820–75) Arnold (1803–90) Hyrtl (1811–94) Henle (1809–85) Sappey (1810–96) Haberer (1901), Quain Roloff Gray Testut Sobotta Tandler Toldt

More recent studies on the artery have been made by Pigache and Worms (1909) Piquand (1910), Lipschutz (1917), Volkmann (1923) Melnikoff (1923) Ssoson Jaroschewitsch (1927) van Goidsenhoven (Lemaire and Debaisieux) (1927) Adachi (1928) Henschen (1928) v *Stubenrauch (1929) and Schabadash* (1935) the latter having studied the splenic artery from a comparative point of view in 255 animals The blood supply of the great omentum has been investigated by Arnaud of France (1927) and Dolgo Saburoff of Leningrad Russia (1927), the former maintaining an independence of the vascularization of the two layers of the great omentum and the transverse colon the latter taking the opposite stand

In terminology the splenic artery has been known as the gastrosplenic (Piquand 1910) and as the pancreatico splenogastric (Farabeuf) Terminal branches of the artery have been named ramus superior and inferior (A v Haberer) a terminalis superior and inferior (Sobotta) ramus lienogastricus for the upper portion of the splenic circulation ramus lienogastroepiploicus for the lower (Henschen 1928) Classical description of the right gastro epiploic was given by Haller The arterial arch around the greater curvature is known as the arcus arteriosus ventriculi inferior of Hyrtl (arcade anastomique sousgastrique of French authors—Rio Branco) The arteria epiploica sinistra first described by Haller is known as the grand rameau epiploique gauch of the French texts The arteria epiploica dextra of Haller is known as the grand rameau epiploique droit of Rio Branco Rossi and Cova The arc formed by the anastomosis of the latter two arteries and found in the posterior layer of the great omentum below the transverse colon is known as the arcus epiploicus magnus of Barkow (described by Haller Luschka Winslow Rio Branco Pigache and Worms Dolgo Saburoff (1927), Arnaud (1927) Henschen (1928)

The transverse pancreatic artery of Haller (of Dolgo Saburoff and of Henschen) which courses along the caudodorsal (inferior) surface of the pancreas to unite with the splenic to the left was termed the inferior pancreatic artery by Testut (Pierson Woodburne and Olsen) *The dorsal pancreatic artery* arising from the first part of the splenic has been named the superior pancreatic by Testut and by Descomps (Pierson)

Piquand (1910) reported that in 32 of 48 bodies the splenic artery divided 2 to 3 cm from the hilus into 2 to 3 large branches which subdivided into 10 to 12 smaller branches In 16 cases the arterial trunk divided at the hilus He observed anastomosis of the splenic artery with the inferior phrenic and with the intercostals Anastomosis between the right and the left gastro-epiploics occurred in half of the cases in the others anastomosis was effected by small branches or not at all The posterior gastric artery arising from the splenic was mentioned as a constant find

Lipshutz of the Jefferson Medical College (1917) in a study of 83 bodies noted that the splenic artery divided into its terminal branches 1 to 7 cm from the spleen 73 per cent had 3 terminal branches (a polaris superior a terminalis superior a terminalis inferior) and 22 per cent had 2 Striking variations comprised a separate origin of the splenic from the aorta (6 cases) the middle colic from the splenic (2 cases) the splenic from the left gastric (2 cases) *Ultimate branches to the spleen varied* from 6 to 10

Melnikoff's work (1923) deals primarily with the intra-organic divisions of the splenic artery. In contrast with the generally adopted opinion, he claimed that the system of intra-organic collaterals in the spleen is well developed, since all arteries anastomose. The larger branches measuring 1 to 2 mm. form vascular arches which are distributed in both longitudinal and cross sections of the organ. Most frequently the arches are single and distributed in the middle of the organ, less seldom in the upper or the lower pole. Short gastrics may take origin from the interior of the spleen.

Volkmann (1923) denied the existence of any important collaterals in the spleen and gave the following divisional patterns of the splenic artery: (1) posterior or at the pancreatic tail, that is, in the pancreas or the back wall of the bursa omentalis (10 per cent); (2) between the pancreatic tail and the splenic hilus (50 per cent); (3) immediately at the hilus (10 per cent).

In a study of 102 bodies, Ssoson-Jaroschewitsch (1927) classified the divisional patterns of the splenic artery into 2 groups: (1) The magistral type, in which the splenic artery is long and divides near the spleen. The branches are large, few (3 to 4) and part in small angles. They reach the center of the spleen as a compact bundle; the hilus is compact and does not exceed one third of the medial surface. (2) The distributed type, in which the splenic artery is short and divides far away from the spleen. The branches are more numerous (6 to 12) and of smaller caliber. They part in larger angles and enter the spleen in a distributed fashion, giving rise to a distributed type of hilus which is never smaller than three fourths of the medial surface and often runs the entire length. Ssoson-Jaroschewitsch maintained that the length of the main splenic trunk up to its lienal division is the only characteristic whereby variations in the splenic arterial blood pattern can be judged. He computed a length index—that is, the ratio of the length of the main splenic in comparison with the total lengths of the splenic vessels extending from the aorta to the spleen. A high index corresponds to a magistral, a low index to a distributed type of vascularization. Between the two types there are endless variations, for the lienal division of the artery may take place at any point between the hilus and the celiac. The fact that a lobulated or indented spleen almost invariably has a distributed type of hilus and blood supply was explained on the basis of embryology, that is, persistence (nonfusion) of original independent and isolated splenic anlages. The magistral type of splenic artery was interpreted as a progressive one. The distributed type is phylogenetically older, conditioned by the original polysplenia of the phylogeny of the organ. In man it represents an inhibited developmental type. The course of the splenic artery is listed by Ssoson-Jarochewitsch of Leningrad, Russia (1927) as being suprapancreatic (90 per cent), retropancreatic (7 per cent), prepancreatic (3 per cent).

Henschen, of the Surgical Clinic of the University of Basel, Switzerland (1928), in a study of 26 preparations of the spleen and the pancreas (radiographic injection) found 2 instances of an intra-organic terminal division of the splenic artery. The extra-organic divisions comprised: (1) a hilus or palm stem group, where division occurred very near the spleen or in a longitudinal groove of the hilus (10 per cent); (2) a peduncular or short distributed type with terminal division occurring between the hilus and the tail of the pancreas about 2 to 3 cm. from the hilus (40 per cent); (3) a parapancreatic or long distributed type with long stem, branching occurring outside the pancreas between its tail and the

celiac artery (16 per cent), (4) an intrapancreatic type, in which the trunk after a short or a long course through the pancreas divides into its terminal branches (3 85 per cent)

Henschen groups the divisional patterns of the splenic artery into magistral and distributed types (Ssoson Jaroschewitsch) the latter type being present in lobulated or polysplenic spleens In most *instances the splenic is tortuous it is* seldom straight Its course is prevailingly *suprapancreatic it may be retropancreatic* prepancreatic and occasionally even intrapancreatic The upper *terminal* branch is termed the ramus lienogastricus the lower the ramus lienogastroepiploicus The splenic branches are often united at the hilus region by outer and inner transversals the zone of the inner transversals being the last to show anastomosis From it branches are distributed to the interior of the spleen which contains only 4 to 10 major arterial compartments these being absolutely delimited During senile concentric atrophy of the spleen the peripheral regions become poorer in blood vessels The left gastro epiploic in some instances takes origin from the interior of the spleen In addition to the typical splenic branches the spleen may receive peripheral branches from the phrenic the lumbar and the internal spermatic arteries

In a study of 252 Japanese Adachi (1928) never observed the splenic artery arising as an independent branch from the aorta He found a ramus gastricus 8 times in 37 bodies arising from the splenic several centimeters medial to its division into the lienal branches The ramus is 1 to 3 mm thick and is distinct from the short gastrics It ascends to the left behind the stomach and branches on the fundus and the upper pole of the spleen No anastomosis was found between *the* ramus *gastricus* and the splenic trunk but at the hilus anastomosis was observed between the ramus gastr*icus* and the uppermost lienal branches With few exceptions the left gastro epiploic was considerably smaller than *the* right gastro epiploic *In most* instances it arose from the lower branch *of the* splenic, *occasionally it consisted* of several smaller branches so that a typical *left gastro epiploic did not exist Adachi* did not investigate the terminal divisional patterns of the splenic artery

Schabadash (1935) made a phylo*genetic study of the splenic artery and* its branches in fish amphibia reptiles birds and mammals, a total of 255 animals having been investigated *He maintained that the key of evolution* can in no way be used to explain the marked differences existing in the size and the form of the spleen and its type of vascularization The splenic artery of non mammals is not homologous with that of mammals It is simple and in many instances represents branches of larger regional arteries namely the a coeliaca the a coeliaca mesenterica gastrica In mammals the splenic artery becomes changed *into* a large vessel which serves many organs the magistral type occurring in those animals in which the main trunk and the branches of the splenic artery supply 3 organs (stomach spleen large omentum) the distributed type occurring in animals in which a fourth organ (pancreas) is supplied

A review of the vast literature *on the* biliary tract would entail a chapter in itself to cover recorded existent variations properly The angular the spiral and the parallel types *of* union of the cystic and the hepatic ducts first classified as such by Ruge (1908) were well illustrated and described by *Eisendrath* (1918–20) after his study of the problem in 100 necropsies at the Cook County Hospital Chicago He compared his findings with those *of previous workers and refers* to the anomalies *of the cystic and the hepatic arteries* as ob

served by Descomps (1910) and Rio Branco (1912)

The anatomic variations of the biliary ducts were investigated by Brewer (1900) Kehr (1902) Sousloff (1907) Ruge (1908) Descomps (1910) Howard and Wohlbach (1911) Kunze (1911) Below (1915) Holmes (1916) Behrend (1919) Palin (1921) Flint (1922) Mc Whorter (1923) Odermatt (1925), Haberland (1926) Ladd (1928) Beaver (1929) Mentzer (1929) Thompson (1933) *Cross* (1936) *Mooseman* and Coller (1951) Johnston and Anson (1952) and many others Boyden of the University of Minnesota has made the major contributions on the variational anatomy and development of the gallbladder and the bile ducts His work and that of many of the cited authors are discussed more fully in Chapter 3

Data on the arterial variations of the small and the large intestine are given in Chapter 12 As regards the appendix and its blood supply it may be noted that from a historical point of view the earliest anatomists as Fallopius Leonardo da Vinci and Andre Wesal (*latinized form of Vesalius*) were concerned with the enteric appendage to the cecum (Vidius an Italian anatomist of the sixteenth century having named it the vermiform appendix) It was Sir Frederick Treves an English surgeon (1853–1923) who suggested the removal of the appendix and Symonds of Guy s Hospital London usually is given the credit for having performed the first appendectomy in 1885 The term appendicitis was first used by Fitz in a paper published in the *Transactions of the American Physicians* in 1886 the phrase previously used being typhlitis or perityphlitis McBurney of New York in 1889 started the modern manner of surgical approach to the appendix he having urged its early removal when pathologically inflamed John Benjamin Murphy of Chicago (1857–1916) who ranks with the Mayo brothers as the most eminent Western crusaders in American surgery advocated a quick removal of the diseased appendix forcefully teaching the axiom Get in quick get out quicker in spreading peritonitis the earlier the surgical interference the better

For prospective young surgeons interested in fundamental orientation as to anatomy blood supply and surgery of the appendix the works of the following authors are suggested McBurney (1889) Fowler (1900) Ochsner (1901) Lockwood (1906) Kelly (1909) *Murphy* (1913) *Aschoff* (1932) Petersen (1934) Wangensteen (1937 1939) Meyer Requarth and Kozoll (1946) Collins (1948) Seshachalem (1948) and Vicari (1954) Informative papers on volvulus of the cecum are those of Jacobsen (1923) Graham (1926) Keef (1932) Sweet (1935) Wangensteen (1942) Eridsen (1947) Gardiner (1947) Gilchrist (1948) Seneque and Courade (1948) Desforges and Wilson (1953) and Wilson Desforges Dunphey and Campbell (1954)

Surgical troubles caused by the spleen and its blood vessels are discussed by Reid of Northwestern University (1954) in his review of 15 splenectomies and confirmed by Zollinger of Columbus Ohio after his experiences with 318 splenectomies

Acute obstructions of the small intestine are associated with arterial complications For an extended discussion of this important disease (the mortality of which is 15 to 20 *per cent*) *the reader is referred to the paper* by Drugas and Schiff of the Michael Reese Hospital Chicago (1954) wherein 154 cases were analyzed The etiologic classification of their cases was as follows

1 Fibrous bands and adhesions (62)
2 Inflammatory adhesions (6)
3 Intussusception (48)
4 Volvulus (6)
5 Intestinal hernia (6)
6 Primary tumor (2)
7 Gallstone ileus (5)
8 Congenital atresia (9)
9 Mesenteric embolus and thrombosis (3)
10 Other causes (7)

Reported arterial variations of the normal pancreas already have been cited Regarding aberrant pancreatic tissue and its pertaining anatomy the reader is referred to the work of Skapinker of the University of Witwatersrand Johannesburg South Africa (1954) who collected from available literature 45 cases of annular *pancreas and* in table form listed author date operation and result of operative procedure in each case

A man can no more do good surgery without anatomical knowledge than a pilot can safely guide his boat without knowing the channel.

—JOHN CHALMERS DA COSTA

3

Embryology, Topographic Relations and Developmental Anomalies

Topographically considered, the transverse colon and the mesocolon separate the abdominal organs into those above them (supramesocolonic) and those below them (inframesocolonic). The supramesocolonic organs are the liver, the gallbladder, the spleen, the pancreas, the stomach and the visible supracolic portion of the duodenum, i.e., the pars superior and the proximal part of the descending duodenum. The inframesocolonic organs are the small and the large intestines and the infracolic part of the duodenum, the latter comprising a section of the descending duodenum and the entire transverse and ascending duodenum. Even when the transverse colon is lifted up and the gut is thrown to the left, because of its retroperitoneal position the infracolic duodenum is usually not visible. However, its contours readily can be brought to view when they are made to swell by blowing air into the pylorus. It will then be seen that this section of the duodenum is firmly attached to the abdominal wall below the attachment of the transverse mesocolon through fusion of its original mesentery (mesoduodenum) with the dorsal body wall and by the suspensory action of the hepatoduodenal ligament, the contained bile duct acting as a major guy rope. It is then crossed by the root of the mesentery of the small intestine, the anchorage point of which to the dorsal body wall varies considerably. In some instances the transverse duodenum sinks to the level of the bifurcation of the aorta.

The complexity and the variational anatomy of the blood supply to the supramesocolonic organs is foreshadowed in the early embryo when these organs are formed. Main phases of this early embryology are (1) establishment of the primitive gut arteries, (2) formation of the primitive gut and its rotation accompanied by structural and positional changes in the pertaining mesenteries, (3) early outgrowth of the primordia of the pancreas and the liver from the gut, (4) retroperitoneal displacement of the duodenum and the pancreas, (5) definitive fixation of the stomach, the spleen and the small and the large intestines.

Arteries of the Primitive Gut

Before the primitive paired dorsal aortae become fused, there is established a bilateral segmental distribution of arteries from the dorsal aortae not only to the body wall and the neural tube (dorsal intersegmental, the future intercostals with their spinal branches) but also to the viscera. Two types of visceral branches are formed: (1) paired lateral

segmental branches (lateral segmental series) which pass under the peritoneum to paired viscera which are primarily retroperitoneal (kidney adrenals gonads) (2) paired ventral segmental arteries (omphalomesenteric) which prolonged into the yolk sac become vitelline arteries Initially they course laterally over the dorsal wall of the primitive gut to reach the yolk sac but after establishment of the mesentery, pass into it to supply the gut and the organs derived from it

By concrescence or obliteration of one artery the two primitive dorsal aortae become a single vessel With the establishment of the midgut a group of paired vitelline arteries (right and left) coursing in its mesentery fuse to become the common superior mesenteric (omphalomesenteric) trunk which supplies the two limbs of the midgut with branches many of which pass around the gut to supply the yolk sac Upon closure of the body wall of the embryo ventrally and the detachment of the yolk sac and the vitelline stalk from the midgut (ileum) the original omphalomesenteric trunk becomes the superior mesenteric artery Cephalad to the group that gave rise to the superior mesenteric artery another group of paired ventral segmental arteries distributed to the infradiaphragmatic portion of the foregut form the celiac artery A similar group of ventral segmental arteries below the level of the superior mesenteric artery distributed to the hindgut fuse to give rise to the inferior mesenteric artery In other words it is by a segmental reduction of the number of original paired ventral segmental arteries and a regional concrescence of those that remain that the three main arteries of the gut become established

The segmentally arranged gut arteries apparently last only a short time and vary in number at different periods Those cranial to the group that gave rise to the celiac disappear very early later those appearing between the omphalomesenteric group and the inferior mesenteric group likewise disappear According to Pernkopf (1922) the 4 mm embryo shows only unpaired visceral branches which are not strictly segmentally arranged At the 8 mm stage all ventral branches of the aorta have disappeared except the roots of the three main gut arteries

The celiac artery becomes established at the level of the twelfth thoracic vertebra and is associated with the dorsal or the posterior mesentery of the stomach and the duodenum The superior mesenteric artery becomes established at the level of the first lumbar vertebra and is associated with the mesentery of the small intestine (jejunum ileum) and portions of the large intestine (ascending and transverse colon) The inferior mesenteric artery becomes established at the level of the second lumbar vertebra and is associated with the remainder of the large intestine (descending colon sigmoid and rectum) The definitive levels of the three main gut arteries are approximately the same as those of the adult body and are attained before the end of the second month

The celiac artery is the largest branch of the abdominal aorta since it supplies all of the supramesocolonic organs Embryologically (4 9 mm embryo) it represents the roots or the proximal ends of the vitelline arteries (omphalomesenteric) near the seventh cervical segment but subsequently (17 mm stage) it is moved caudally to the twelfth thoracic vertebra (Mall) In the reconstruction of a 17 8 mm human embryo made by Thyng (1914) the celiac artery arises from the aorta slightly caudal to the eleventh thoracic dorsal intersegmental arteries where it immediately divides into the left gastric the splenic and the hepatic Bremer of Harvard University (1926) gave an extensive account of the

influence which nerves exert on the position of the celiac artery in the chick

According to Pernkopf (1922) the definitive stem of the celiac artery is visible as early as the 5 mm stage Arising with two or three roots then with only one root the origin of the artery wanders 10 segments caudally so that in the 14 mm embryo it is already at the level of the ninth thoracic segment Its branches may be followed in the 10 mm embryo Tandler s observations on the origin of the celiac will be presented later

The superior mesentery represents the roots or the proximal ends of the vitelline arteries in the region of the first three thoracic segments ultimately displaced 10 segments caudally to the first lumbar vertebra As it passes into the mesentery of the primitive unrotated umbilical midgut loop it gives off right (anterior) branches to the duodenum the pancreas the jejunum and the ileum and left (posterior) branches to the colon After rotation of the midgut loop (which occurs around the superior mesenteric artery the latter rotating about 180°) the arterial supply of the gut is reversed Branches to the small intestine now arise from the left convex side of the superior mesenteric trunk branches to the colon arise from the right side there being one exception—viz the inferior pancreaticoduodenal which continues to arise from the right side as the first branch of the superior mesenteric because rotation of the gut took place distal to its origin (Huntington 1903)

The inferior mesenteric artery represents the most caudal roots (one or two) of the vitelline arteries displaced subsequently to the level of the second lumbar vertebra Its main branch the left colic unites with the middle colic which after rotation of the gut becomes the second right branch of the superior mesenteric the third and the fourth branches being the right colic and *the ileocolic arteries* The inferior pancreaticoduodenal remains the first branch of the superior mesenteric for as stated previously rotation of the gut occurs distal to it in most instances If rotation occurs proximal to it the artery will arise from the left side of the superior mesenteric or from a jejunal branch as shown in many of the author s illustrations

Noteworthy is the fact that the caudal migration of the origin of the gut arteries while accompanying the caudal migration of the gut is decidedly not so extensive as the latter It is because the caudal (downward) shift of the origin of the superior mesentery is not so pronounced as that of the pertaining gut which it supplies that the stem of the superior mesenteric artery has a very abrupt descent in the mesentery and has a relation with the pancreas The same is true of the celiac its origin being more cranial than the gut it supplies

Formation of a celiacomesenteric trunk (i e a trunk in which all of the branches of the celiac artery or one or more of its branches—left gastric splenic hepatic gastroduodenal—arise from the superior mesenteric) has been explained by Tandler (1904) on the following basis In early human embryos (4 to 17 mm) the omphalomesenteric artery (superior mesenteric) arises by 4 roots (10 11 12 13 ventral segmentals) which are united by a ventral longitudinal anastomosis running parallel with the aorta Normally the greater part of this ventral longitudinal anastomosis disappears as do the two middle roots (11 12) leaving the first root to become the stem of the celiac and the last root to become the stem of the superior mesenteric If the roots which should have given origin to the celiac undergo retrogression while the ventral longitudinal anastomosis persists a celiacomesenteric *artery is formed* as is phylogenetically the case in *Talpa europea* Normally the 3 main branches *of the celiac arise in series successively*

from the cranial end of the longitudinal anastomosis thus accounting for the fact that the left gastric arises proximal to the origin of the hepatic and the splenic If the ventral anastomosis is interrupted between the left gastric and the splenic—i e if the first and the last roots persist along with the greater part of the longitudinal anastomosis—then the left gastric will arise separately from the aorta the splenic and the hepatic from the superior mesenteric If the longitudinal anastomosis is interrupted between the splenic and the hepatic the former arises from the aorta along with the left gastric the latter from the superior mesenteric In short the ventral longitudinal anastomosis between the roots of the primitive vitelline arteries is the common source of origin of all the branches of the celiac artery and of the accessory hepatic arteries persistence of interrupted sections accounting for aberrancy in origin of the regional arteries

Establishment of the Primitive Gut the Visceral and Parietal Peritoneum and the Mesenteries

Long before the body of the embryo becomes folded off from its extra embryonic membranes the primitive gut is already established in a foregut a midgut and a hindgut The foregut extends cephalad under the head fold and terminates at the buccopharyngeal membrane The midgut at first opens ventrally into the yolk sac but later becomes separated from it and projects (herniates) into the extra embryonic celom of the umbilical cord as a free loop which dorsally is suspended from the body wall by a mesentery but ventrally has the vitello intestinal duct attached to it The hind gut extends under the tail fold a dilated portion of it (the cloaca) receiving the allantois

The foregut gives rise to the pharynx the esophagus the stomach the first part and the upper one half of the duodenum the liver and the biliary system the pancreas and the laryngotracheal outgrowth (epithelial lining and glands of the respiratory ducts), while part of its dorsal mesentery through local proliferation of its mesenchymal cells gives rise to the spleen The midgut loop gives rise to the lower half of the duodenum to the small intestine to the ascending and most of the transverse colon (right and middle thirds) The hindgut gives rise to the remaining colon (the left third of the transverse colon the splenic flexure the descending colon the sigmoid colon) and the rectum The dividing point between the small and the large intestines is indicated very early by a small antimesenteric swelling on the lower limb of the umbilical midgut loop this being the anlage of the future cecum and the appendix

Body Cavities Differentiation of the three primary body cavities (pericardial pleural and peritoneal) proceeds from the primitive common right and the left intra embryonic celomic cavities These are continuous with those of the extra embryonic celom and become established by the splitting of the lateral mesoderm into splanchnic and somatic layers Later through a folding off process of the embryo from the yolk sac the two primary celomic chambers are brought into the midline and the primitive digestive tube becomes lodged between the two layers of splanchnic mesoderm which respectively bounded the medial walls of the original double celom This medial septum of the splanchnic mesoderm containing the gut becomes thinned out to form the ventral and the dorsal mesentery The splanchnic mesoderm gives rise to the visceral layer of the pericardium the pleura and the peritoneum (the latter including the visceral layer of the gut and its mesentery) the somatic mesoderm furnishes the parietal layers of the three respective cavities

The dorsal mesentery extends from the lower end of the esophagus to the cloaca It assumes different names in successive regions of the gut viz mesoesophagus mesogastrium mesoduodenum mesentery mesocolon mesorectum Many sections of the dorsal mesentery disappear through fusion with the dorsal body wall when parts of the gut become retroperitoneal It is through fusion of the visceral peritoneal layer of the gut and its mesentery with the parietal peritoneal layer that portions of the primitive gut become retroperitoneal The process may be conceived as follows

If a book is opened the inside of the cover may be pictured as representing the parietal peritoneum and the first page as representing the visceral peritoneal layer of the gut and its mesentery If now the first page is turned to the left and pasted to the inside of the cover its visceral peritoneal layer is lost—i e is changed to connective tissue and becomes fused with the parietal layer In such fashion certain parts of the gut along with the pertaining mesentery and organs associated with it (duodenum and pancreas) become similarly retroperitoneal the newly acquired peritoneal covering representing one side of the original visceral peritoneal reflection Because of the 270° rotation of the gut certain sections of it (along with the respective mesentery) fall to the right other sections fall to the left of the midline and become fused with the parietal peritoneum of the posterior body wall Certain sections of the gut retain their mesenteries these being thrown transversely (transverse mesocolon) or obliquely (root of small intestine) across the abdominal dorsal wall thereby attaining a new attachment for them

The ventral mesentery is the splanchnic mesodermal sheet of the original celom which extends from the primitive gut to the anterior abdominal wall It breaks through early below the umbilicus level and disappears entirely except in the region of the developing liver where it persists and eventually gives rise to the lesser omentum and the falciform ligaments

The pericardial cavity is the first to become walled off from the primitive celom by paired pleuropericardial partitions thereby affording room for the developing heart On either side of the heart and dorsal to it the developing lung buds expand into a portion of the primitive celom known as the pleural canals which subsequently enlarge and become walled off as the pleural cavities The peritoneal cavity is the last to be walled off Cephalad, this is accomplished by the septum transversum (primitive diaphragm) and the paired pleuroperitoneal folds joining it Ventrally it is accomplished by closure of the ventral belly wall through separation of the embryo from its extra embryonic membranes

Wells of the Anatomical Institute of the University of Minnesota (1954) has made a *surprisingly complete reinvestigation* of the development of the diaphragm and the pleural sacs a phase of embryology nearly completely neglected for the past four decades (Contributions to Embryology No 236 Carnegie Institution of Washington vol 35 pp 107–134 1954) The work of Wells conducted for the most part at the Carnegie Institution with the sustaining interest of Dr Corner its director is based on a study of 255 sectioned embryos of the Streeter group transparent and plaster models and 12 preserved human embryos Anatomic relations were investigated from a *three dimensional point of view* and are copiously illustrated in 33 figures

Wells suggests that the term septum transversum should be used to refer to that bridge of mesoderm in which the liver grows As development proceeds it

contributes cells to diaphragm falciform ligament liver gallbladder lesser omentum ventral pancreas duodenum and stomach In embryos with 30 paired somites it consists of a pars diaphragmatica a transverse shelf to which the liver is attached its upper surface being covered by primitive diaphragmatic pericardium and pleura and a pars mesenterica ventralis a median sagittal part which has been expanded by the liver which it contains

In view of the important bearing the classically achieved work of Wells has on the origin and the cause of congenital diaphragmatic hernias (pleuroperitoneal esophageal sternocostal lumbocostal) the conclusions arrived at are cited in full

The primitive diaphragm may be regarded as a single structure with six blended regional subdivisions and with five hiatuses three permanent and two temporary Its blended subdivisions are the transverse septal (including the gastrohepatic caval and sternal parts) membranous (pleuroperitoneal membranes) costal retroglandular aortic and mesogastric Its permanent hiatuses are the caval esophageal and aortic Its temporary hiatuses are the pleuroperitoneal canals

The observations seem to indicate (1) that the transverse septal subdivision produces the pars sternalis and portions of the pars costalis and pars lumbalis (2) that the right and left membranous subdivisions become only very small segments of the pars costalis (3) that the pleuroperitoneal hiatuses (canals) and pleuropericardial canals are crowded out of existence by the growth of the subjacent organs (4) that Bochdalek s lumbocostal triangles do not mark the sites of closure of the pleuroperitoneal hiatuses and (5) that pleuroperitoneal hiatus hernia and the so-called congenital absence hernia (absence of a dorsolateral segment of the diaphragm) are two grades of the same congenital anomaly namely abnormal persistence of the pleuroperitoneal hiatus

Rotation of the Stomach Formation of the Lesser Omentum the Great Omentum and the Omental Bursa

The following is the standard account of the development of the omental bursa as variously described in textbooks and adopted in didactic lectures However according to Broman [1] of the University

[1] Broman of Sweden (1904) extensively studied the mode of development of the bursa omentalis in reconstruction models of a wide series of human embryos (mm 11 7 mm 70 mm etc) As stated in his embryology text the simple arrangement of a complete dorsal and incomplete ventral mesentery soon becomes altered by the development of pocketlike mesenteric recesses One appears on the left three on the right The left one the recessus pneumato-entericus sinister in a 3 to 4 mm embryo separates the caudal portion of the left mesodermal lung anlage from the intestinal tract but soon undergoes complete retrogression

The three right mesenteric recesses comprise the recessus pneumato entericus dexter the recessus hepato entericus and the recessus pancreatico entericus Respectively considered they isolate the lung the liver and the pancreas from the digestive tract The three differently directed right sided pocketlike mesenteric recesses at first have separate openings Later that part of the greater peritoneal cavity adjoining the openings is drawn into the recess formation by the fact that the liver grows into the caudal portion of the mesodermal lung anlage shifting the latter caudally as it enlarges In this way the three mesenteric recesses become confluent into a single large pocketlike pouch which has but one opening (foramen of Winslow) and is the common anlage of the bursa omentalis and of the infracardiac bursa

With the development of the diaphragm the walls of the primitive recessus pneumato entericus dexter become pressed together and fuse Thereby the cranial portion of the united mesenteric recesses becomes cut off to form the infracardiac bursa while the caudal portion remains as the bursa omentalis The purpose of the infracardiac bursa is to isolate the right lung from the gut tract a function it still maintains in many mammals where a well-developed cavity (the third pleural cavity) isolates the infracardiac lobe of the right lung from the esophagus In man the infracardiac bursa loses its primitive significance *and assumes* a new function As a demonstrable small space between the diaphragm and the esophagus it effects an easy passageway for the esophagus *through the* diaphragm

Subsequent development of the bursa omentalis and formation of *the great omentum* and the lesser omentum proceeds as follows when the stomach in its caudad descent reaches the level of the celiac

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of Lund (1927), the origin of the bursa omentalis (lesser peritoneal cavity) is absolutely independent of the positional changes of the stomach though they influence its form and location markedly The leftward shift *of the stomach* in Broman s opinion most probably is due *to the asymmetrical* growth of the two liver lobes

It was Johannes Muller (1830) who first gave the concept that the bursa *omentalis arose through a leftward shift* of the *position of the stomach* and its dorsal mesentery and that *its primitive* large opening was made *smaller by the* shift of the pylorus Despite contravening evidence Muller s *concept has been* followed in practically all textbooks and is still the standard and the simplest way of teaching *the mode of origin of the* omental bursa As *early as 1880 His* showed that in a 7 mm embryo *the* bursa *omentalis* arises as a right sided mesenteric recess Swaen (1897–99) was the first to show that in man the mesen*teric recess formation is altered by posi*tional changes of the stomach With this in mind the didactic approach is as follows

By the end of the fourth week a spindle shaped dilation of the primitive *foregut dorsal to the developing heart* indicates the position of the stomach At *the sixth week* through elongation of the esophagus *the stomach has moved* downward and has largely assumed the shape of its adult form *its* cardiac region being somewhat more dorsal than the pyloric As seen at this stage the stomach and the remainder of the gut are sus pended from the dorsal body wall in the *midline by the* dorsal mesentery which extends to the cloaca The ventral mes entery extends only to the umbilicus since it is lacking below the first inch of the duodenum

A more rapid rate of growth of the dorsal wall *of the stomach along with* a leftward rapid saclike expansion of its *mesentery (dorsal mesogastrium) causes* the stomach to rotate to the left on its longitudinal axis through 90° Thereby *the lesser curvature* and pyloric end of *the stomach is turned to the right* the greater curvature and cardiac end is shifted to the left The original sagittal dorsal *mesogastrium* with a right and a left dorsal surface assumes a frontal posi tion and becomes bulged out into a two walled sac *the primitive great omentum* the posterior wall of which contains the developing pancreas (body and tail) the *anterior wall near the stomach contains the developing spleen* Each wall (ante rior and posterior) of the primitive great *omentum* (sac of dorsal mesogastrium) *has a lamina propria composed of con*nective tissue and two serosal layers—an *inner representing* the *right side an outer* representing the left side of the original dorsal mesogastrium The in terior of the primitive omental sac even *tually will become* part of the omental bursa (lesser peritoneal cavity) The original sagittal ventral mesogastrium which *extends* from the stomach to the

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artery the latter along with its hepatic branch (the hepatic artery)) raises a *fold—the plica arteriae* coeliacae—which divides the omental bursa *into* a left *and a right compartment* respectively known as the major and the *minor* omental bursa Ini tially the minor omental bursa is not delimited extensively by the *ventral mesentery the latter* being but a short connection between the liver and *the stomach Later however when the caudate lobe of the* liver grows and projects *to the left the primitive short ventral mesentery becomes stretched out to form the* lesser *omentum In embryos of* about 5 *cm in length* the wall of the great omen *tum along the greater curvature grows rapidly and* extensively in a caudad direction thereby forming *the great omentum From the fourth to the eighth* months the great omentum is relatively short *separating only the dorsocaudal surface of the liver from the gut It is only during the last two months* that the great omentum lengthens to the level of *the umbilicus thereby intervening between the* body wall and the gut tract Expansion of the *omental bursa occurs concomitantly with the* growth of the great omentum and is directly pro *portional to it*

ventral body wall and which contains the developing liver likewise assumes a frontal position with the rotation of the stomach and ultimately will give rise to the lesser omentum (hepatogastric, hepatoduodenal ligaments), the falciform ligament and the coronary ligaments of the liver

The massive growth of the liver in the septum transversum and its downward projection into the ventral mesentery, along with *the process of descensus viscerum*, accelerates the descent of the growing stomach. Since its pyloric end is relatively fixed by the hepatoduodenal ligament and its contents (especially by the bile duct), while its cardiac end is free, the stomach undergoes another rotation of 90° on an anteroposterior axis whereby its longitudinal axis is shifted to a transverse one. In short, the stomach assumes its definitive oblique position across the abdomen from left to right, the lesser curvature facing cephalad, the greater curvature caudad. The posterior layer of the omental sac formed by the dorsal mesogastrium which contains the pancreas and the splenic vessels and which extends from the vertebral column to the lateral margin of the left kidney (the latter protruding retroperitoneally) becomes fused with the parietal peritoneum of the posterior abdominal wall, thereby placing the pancreas and the greater part of the splenic artery in a retroperitoneal position. Those parts of the dorsal mesogastrium above the pancreas which do not fuse with the posterior abdominal wall become the phrenicogastric and the phrenicolienal (pancreaticolienal) ligaments, the former connecting the stomach, the latter the spleen with the dorsal body wall. The cephalic portion of the secondary root line (attachment of the dorsal mesogastrium) therefore extends from the cardiac end of the stomach to the tail of the pancreas

The original dorsal wall of the omental sac (dorsal mesogastrium) which hangs apronlike below the pancreas over the underlying upper surface of the transverse mesocolon and the transverse colon becomes fused with them, thereby making them constituents of the great omentum (posterior wall of the omental sac) and giving to the transverse mesocolon (now the pars mesocolonica omenti) a new attachment to the caudal anterior surface of the pancreas. The part of the transverse colon that becomes fused to the back wall of the great omentum lies between the cranial taenia mesocolica (site of attachment of the transverse mesocolon) and the ventral taenia omentalis (site of attachment of the great omentum and the gastrocolic ligament). To the right, a part of the transverse mesocolon, viz. that which overlies the descending duodenum, becomes fused with the latter, thereby rendering this first part of the transverse colon fixed (pars fixa), whereas the rest of it remains free (pars libera). Caudad to the transverse colon, the posterior layer of the omental sac remains free (pars libera omenti), then turns upward distally to form the anterior layer of the omental sac (great omentum), both layers overlying the small intestine. The gastrocolic (gastromesocolic) ligament continues the anterior layer of the great omentum to the stomach, where it splits to form the anterior and the posterior serosal layers of the stomach, then continues onward from the lesser curvature to the liver as the lesser omentum (gastrohepatic ligament). The gastrolienal ligament continues the anterior layer of the great omentum from the stomach to the spleen

In the adult, therefore, the great omentum caudad to the attachment of the transverse colon, when unfused, consists of 4 serous layers (an outer and an inner for the anterior wall, an outer and an inner for the posterior wall), while above the transverse colon it is com

posed of 6 serous layers 2 of which have become eliminated (i e reduced to connective tissue by the fusion of the dorsal mesogastrium with the transverse mesocolon)

The omental bursa (lesser peritoneal cavity) is *the interior of the omental sac* formed by the great omentum and the lesser omentum It is but a part of the greater peritoneal cavity which became folded off by the leftward shift of the stomach and the sacculation of its dorsal mesogastrium and the rightward shift of the ventral mesogastrium (lesser omentum) and the latter s transposition into a frontal plane In every direction the bursa (cavity) is lined by the right side of the original dorsal and ventral mesogastrium for with the exception of the mesoduodenum it is only the left side of the primitive dorsal mesentery that fuses with the posterior abdominal wall The original wide communication between the two peritoneal cavities to the right becomes reduced to a small opening (epiploic foramen) by the massive growth of the liver and by the fixation of the duodenum

The subdivisions of the bursa omentalis as masterfully and clearly outlined by Pernkopf Professor of Anatomy Vienna University (1943) comprise

1 The large retrogastric space (cavum retrogastricum) It may readily be seen when the gastrocolic ligament is cut along the greater curvature and the stomach is lifted up As the actual omental bursa it lies behind the stomach up to the fundic region or to that part of the dorsal mesogastrium which as the phrenicogastric ligament connects the dorsal wall of the stomach with the diaphragm Caudally it extends behind the gastrocolic ligament into the inferior or caudal recess the depth of which varies as will be shown shortly

The ventral freely movable wall of the retrogastric space is made by the free dorsal wall of the stomach only the fundus lying cranially *outside it* The dorsal wall presents the fixed body and *the tail of the pancreas* covered by the secondary parietal peritoneum made by the fused dorsal mesogastrium A fold of the latter above the distal end of the pancreas (plica lienalis) contains the tortuous twisted splenic artery and sometimes its primary division into its two terminal branches or an accessory left gastric artery springing from the splenic The dorsal and the ventral walls of the retrogastric space touch each other and are often partly *fused through adhesions* which must be severed to see the space *The gastrocolic ligament itself* may be fused to the back wall of the omental sac

2 The splenic recess (recessus lienalis) It continues the omental bursa leftward to the hilus of the spleen and is bounded anteriorly by the relatively fat free gastrolienal ligament posteriorly by the phrenico (pancreatico) lienal ligament in which a small (1 cm) accessory spleen may be lodged The two ligaments are often fused near the spleen forming for the latter a flat splenic pedicle which likewise may contain a pea shaped accessory spleen freely movable or packed in a hilar fossa of the spleen The splenic recess is relatively large and since it is rarely obliterated by adhesions offers an excellent approach to the retrogastric space and to the left gastric epiploic artery coursing in the gastrolienal ligament

3 An inferior or caudal recess (recessus caudalis colicus) Hereby the omental bursa is extended caudally below the greater curvature and behind the gastrocolic (gastromesocolic) ligament The back wall of this recess is entirely free and movable and is a constituent not only of the greater omentum (dorsal mesogastrium) but also of the mesentery of the transverse colon i e the transverse mesocolon which from the caudal anterior border of the pancreas down

ward fuses with the dorsal mesogastrium

The depth and the dimension of the inferior omental recess vary considerably. In most individuals the recess is more or less obliterated due to the partial or complete fusion of the anterior and the posterior walls of the greater omental sac. The recess may extend caudally to the line of attachment of the transverse mesocolon (along the caudal [anterior] border of the pancreas) or to the transverse colon itself—i e to the taenia omentalis to which the gastrocolic (gastromesocolic) ligament is attached. When the gastrocolic ligament itself is fused with the back of the omental sac there is practically no inferior recess. When entirely open as in the newborn and in some adult individuals the inferior recess extends over (anterior to) the transverse colon into the free part of the great omentum reaching the latter's free border. In such instances only the dorsal wall of the omental sac (dorsal mesogastrium) becomes fused with the transverse mesocolon the colon itself fusing with it between the taenia omentalis and the taenia mesocolica. Caudal to this fusion point the posterior wall of the omental sac remains free and unfused (pars libera omenti) up to its distal end whereupon it turns forward to become the free unfused ventral wall of the omental sac. This continues cranially as the gastrocolic (gastromesocolic) ligament attaching itself to the greater curvature of the stomach

4 The vestibule of the bursa omentalis (cavum paragastricum) This large forespace of the bursa lies behind the flaccid netlike portion of the lesser omentum and is co extensive with it. The tuber omentale of the left lobe of the liver overlies it and the tuber omentale of the pancreas which bulges forward over the vertebral column underlies it. If the netlike lesser omentum is torn asunder it will be seen that the anterior wall of the vestibule is made by the hepatogastric ligament its posterior wall by the secondary parietal peritoneum (primitive dorsal mesogastrium) fused to (covering) the pancreas. To the right the vestibule leads to the epiploic foramen of Winslow whereby communication is established with the greater peritoneal cavity. In this region the dorsal lamella of the coronary ligament becomes continuous with the parietal peritoneum which forms a plica over the inferior vena cava and extends over the kidney capsule as the hepato cavoduodenal ligament. The latter overlies that part of the dorsal surface of the right lobe of the liver which is intimately bound down to the dorsal body wall

To the left the vestibule leads into a narrow passageway the isthmus of the bursa (isthmus bursae) bounded by two peritoneal folds of the dorsal body wall which proceed upward from the head of the pancreas. One fold is cranial and arches to the left to the cardiac end of the stomach. This gastropancreatic fold (plica gastropancreatica) contains the left gastric artery and the coronary vein thereby affording a means whereby the left gastric passes from the dorsal to the anterior wall of the omental bursa. The other fold (plica hepatopancreatica) ascends to the right where it joins the hepatoduodenal ligament derived from the ventral mesoduodenum. This fold contains the common hepatic artery carrying it from its origin from the celiac artery behind the posterior wall of the bursa to the hepatoduodenal ligament whereby it reaches the liver

5 A superior recess (recessus cranialis) This extends upward from the vestibule behind the caudate lobe along the right side of the abdominal esophagus to the diaphragm. Its right wall is made by the papillary process which projects into the bursa as may readily be

ascertained when a finger is passed through the epiploic foramen

The size and the consistency of the great omentum vary considerably When transparent it has a thin netlike appearance with numerous narrow strips of fat disposed along the blood vessels That part of the great omentum which hangs down from the transverse colon usually has no generalized cavity (bursa) due to the fusion of the anterior and the posterior walls (from taenia omentalis downward) Since this fusion process is more marked on the right than on the left side of the great omentum remnants of the cavity (free bursal pockets) may be present between the layers on the left side especially in the upper left quadrant above the transverse colon Here the anterior layer gradually becomes entirely *free to form the gastrolienal ligament* To the left the anterior layer becomes the gastrocolic ligament which remains free but also is often fused

In many individuals the fused anterior and posterior layers become infiltrated with fat sometimes forming a mass an inch or more in thickness The pars libera of the great omentum may hang down like an apron into the pelvis it may be very short extending but a few inches below the transverse colon In some instances it is lacking or adherent to the ascending colon To the left of the greater curvature of the stomach the anterior layer of the great omentum (i e the gastrolienal ligament) may form an apronlike appendage which becomes inserted between the stomach and the spleen or it may form a veil covering the spleen *(lienal omentum)* Rounded up portions of the great omentum may become adherent to the ventral body wall or to the small intestine or they may protrude into an inguinal or an umbilical hernia *Not infrequently* the pars libera is wrapped around the gallbladder most of it being confined to the right side of the body

The epiploic foramen of Winslow opens into the vestibule of the omental bursa It lies between the liver and the duodenum below the gallbladder in a niche (space) formed by the liver the colon the duodenum and the kidney Its immediate boundaries are ventrally the dense hepatoduodenal ligament which constitutes the hepatic pedicle carrying the hepatic artery the bile duct and the portal vein superiorly the tail of the caudate lobe inferiorly the pars superior of the duodenum posteriorly the vena cava inferior covered by parietal peritoneum The foramen may be partly closed or it may be shifted more to the right or otherwise modified by peritoneal folds associated with the lesser omentum and connecting the liver and the gallbladder with the duodenum or *the transverse colon* (cystoduodenal cystocolic cystohepatic ligaments) the normal (congenital) or the pathologic character (inflammatory adhesions) of which is still debated most authors interpreting them as congenital formations (McConnell and Hardman 1923 Behrend 1927 as conceived by Schaeffer)

Rotation of the Gut Its Definitive Fixation and Anomalies

The duodenum in its original primitive midsagittal position has a complete dorsal mesentery the mesoduodenum into which grow not only the dorsal but *also the ventral pancreas and into which* the celiac artery extends Because of this pancreatic growth the mesoduodenum rapidly expands into a thickened mass During gastroduodenal rotation when *the stomach turns to the left the duodenal* loop turns to the right and the original right side of the mesoduodenum becomes fused with the parietal peritoneal layer of the body wall thereby placing the duodenum in a retroperitoneal position Its point of attachment to the posterior abdominal wall constitutes the trunk of the mesentery (truncus mes

entericus Pernkopf) to which is attached cranially the dorsal mesogastrium caudally the common mesentery of the small and the large intestines and to the right a part of the ventral mesentery (hepatoduodenal ligament) Later when the transverse colon crosses the second part of the duodenum its mesentery (transverse mesocolon) fuses with the duodenum thereby giving the latter a secondarily acquired peritoneal reflection Only a small section of the first part of the duodenum retains a relatively complete peritoneal covering and is freely movable as the pylorus The ventral mesentery of the duodenum is small and is restricted to the first inch of the duodenum It becomes the hepatoduodenal ligament through which course the hepatic artery the bile duct and the portal vein The hepatoduodenal ligament is the dense free margin of the lesser omentum its other thin netlike component being the gastrohepatic ligament

Below the duodenum the ventral mesogastrium is absent The midgut is thrown into an umbilical loop which projects forward (ventrally) into the extra embryonic celom of the umbilical cord In its midsagittal position it is firmly attached to the posterior wall by a dorsal mesentery through which courses the superior mesenteric artery The U shaped loop has an upper and a lower limb situated respectively above and below the yolk stalk (vitello intestinal duct) to which it is attached for a short period If attachment persists a Meckel s diverticulum of the ileum is formed (6 to 18 inches from the ileocecal junction) The upper loop and a part of the lower loop of the midgut give rise to the jejunum ileum the lower limb becomes the ascending and the greater part (two thirds) of the transverse colon A small swelling on the lower limb indicates the position of the cecum and marks the division between the small and the large intestines The cranial (upper) end of the loop becomes the duodenojejunal flexure the caudal (lower) end marks the position of the primary left (splenic) flexure from which proceed the descending colon and the sigmoid colon The convexity of both flexures faces dorsally the flexures being fixed to the posterior abdominal wall by thickenings of the mesentery known respectively as the proximal and the distal retention bands

The more rapid growth and elongation of the small intestine represented for the most part in the upper limb causes the umbilical midgut loop to rotate counterclockwise (ventrally viewed) on its longitudinal axis formed by the superior mesenteric artery the artery itself rotating 180° In this right sided rotation (dextrotorsion) the upper limb of the loop is thrown to the right to allow the caudal loop to ascend and to cross it thus placing the loops in a position the reverse of that they originally had Since the crossing segment of the caudal loop ultimately becomes the transverse colon it follows that the jejunum the ileum and part of the duodenum come to lie caudal to the transverse colon and its mesenteric attachment Before and during the twisting of the umbilical loop the left colon (splenic) flexure becomes more pronounced and is lifted upward toward the left thereby allowing room for the duodenojejunal flexure to move to the left

Following the dextrotorsion (counter clockwise twisting) of the umbilical loop the small intestine grows faster and more extensively than the large intestine Its length increases to such an extent that by the end of the seventh week because of lack of space in the belly cavity it escapes (i e herniates) into the extra embryonic celom of the umbilical cord where it forms 6 primary loops (Mall 1897) Later at the tenth week (42 mm stage) when the body of the embryo has

enlarged sufficiently to allow room for the expanded gut mass the small intestine is suddenly pulled back into the abdominal cavity through the umbilical ring[2] The returned coils of small intestine fall into the right iliac fossa and *gradually push the lower portion of the* colon (which because of its slower growth never left the body cavity) still more to the left The cranial or cecal end of the colon which did protrude into the umbilical celom is the last section to re enter the body cavity perhaps because of its cecal swelling As it enters it is *thrown to the right side under the liver* and over the coils of the small intestine thereby completing the dextrorotation of the gut begun at the time of the herniation of the primitive midgut (the first to be looped) into the extra embryonic umbilical celom As the cecum abuts against the right body wall its concavity is directed cephalad *and to the right and the* terminal ileum enters the colon from the right to the left But after rotation of the cecum (i e after it turns downward) *its concavity faces* caudally and to *the left and the terminal ileum enters* the colon from the left to the right as normally the case in the adult (Huntington) *With the caudalward bend of the cecum the first anlage of the ascend*ing colon is formed In later stages the *cecum descends lower and lower with relative diminution in the size of the liver until it reaches its definite position* in the right iliac fossa[3]

Regarding the rate of gut growth Broman (1927) *found that at first the* large intestine is very long constituting about one half of the gut length Up to *the end of the third month however the growth of the small intestine* (especially of the iliac coils in the extra embryonic umbilical celom) *exceeds that of the* large intestine *to such an extent that by the end of this period* the large intestine measures one eighth of the entire gut length Subsequently the large in*testine takes on a faster rate of growth* attaining at the eighth month about one sixth *of the length of the entire gut* this being the approximate proportion in the adult body

[2] Cause *for the sudden return of the gut is un*known According to Broman (1927) reposition of the gut in the body cavity is caused by the great *enlargement of the liver During the first half of the third month its ventrocaudal border* becomes shifted to the level of the pelvis on both sides *The* gut loop is thereby pressed caudalward by the liver so much so as to overcome the forces in the navel hernia which prevent reposition *A dorsoventral* enlargement of the liver likewise assists in the process of reposition

[3] Richard Hunter of Queen s University Belfast (1929) *after a study of a series of human fetuses* and adult cadavers concluded that the common opinion that the ascending *colon is formed as the* cecum descends is erroneous In a fetus of 6 cm length after the intestines have been withdrawn from the umbilical cord the ileocecal junction is not high up in the abdominal cavity but along with the *liver is placed well down close to the* level of the highest point of the iliac crest After its withdrawal from the umbilical *celom the devel*oping colon does not pass from right to the left as commonly taught but instead passes *obliquely* from the right iliac crest below the lower pole of the right kidney upward and to the left to the splenic flexure (13 5 cm embryo) As the *colon in its* ascent to the left crosses *the second* portion of the duodenum it *forms* an adhesion with it This adhesion is an important landmark for the curved *segment of the colon* between it and the cecum *anlage form* the whole of the ascending colon and that part of the transverse colon situated between *the adhesion point and the hepatic flexure* The bulge on the anterior wall of the cecum gives the appearance of a downward movement but this is *more apparent than real being simply* the flowing over" of an *irregularly* developing sac the cecum fixed by its ileocecal junction Through a *rotation of the ascending colon from left to right its mesocolon* becomes fused with the posterior abdominal wall If this rotation does not occur a mesocolon (*i e mobile ascending colon*) is formed Proof that the ascending colon actually rotates to the right is forthcoming *from the direction* of the longitudinal taenia in the adult body for here the ventral band of the longitudinal muscle fibers in the transverse colon curves around at the hepatic *flexure and appears* on the right dorsolateral surface of the ascending colon while the ventral longitudinal band on the ascending colon bends below the hepatic flexure and appears *on* the infradorsal *surface of the transverse colon*

In criticism of Hunter s contention *it may be* stated that very *frequently* the author has seen the ileocecal junction lying high *up in the* abdominal cavity in newborn babies and in *fetuses* of different ages

These changes in the form and the position of the gut are accompanied by comparable changes in the dorsal mesentery. The mesentery of the umbilical gut loop, i.e., the common mesentery of the small and the large intestines, during dextrorotation of the loop and the leftward shift of the duodenojejunal flexure undergoes a right sided rotation along its longitudinal axis (about the superior mesenteric artery). When dextrorotation is completed, the common mesentery has a long-drawn-out, funnel shaped appearance, with only a portion of it thrown into a frontal plane. Part of the original left side of the mesentery faces the dorsal body wall, part of it faces the great omentum. The mesentery of the appendix (mesenteriolum), which proceeds from the dorsal side of the common mesentery, is to be regarded as a left mesenteriolum. As the trunk of the mesentery is being formed through fusion of the thickened pancreas laden dorsal mesoduodenum to the body wall, the attachment of the common mesentery to the dorsal wall becomes progessively shorter, so that finally it appears to rise only from the left side of the mesenteric trunk (truncus mesentericus).

By the end of the fifth month the ascending colon and the first part of the transverse colon lose their mesenteries, for they become fused with the dorsal body wall and with the duodenum lying behind it. At the same time the mesentery of the descending colon becomes frontally disposed, then fuses with the dorsal body wall, while that of the sigmoid colon remains free and runs an oblique course as the mesosigmoid. The original primary mesentery of the transverse colon (transverse mesocolon) along with the wall of the transverse colon situated between the taenia mesocolica and the taenia omentalis becomes fused with the dorsal mesogastrium, i.e., the dorsal wall of the great omentum, thereby giving this secondary transverse mesocolon a new attachment to the posterior body wall. In its definitive form the attachment of the transverse mesocolon extends from the head of the pancreas along the caudal anterior surface of the pancreas to the tail end of the organ, where it becomes continuous with the root line of the dorsal mesogastrium. The definitive attachment of the root of the mesentery of the small intestine (jejunum and ileum) extends from the second lumbar vertebra at the left of the midline to the right iliac fossa (fourth lumbar vertebra), where it joins the fixed ascending colon. If the distal end of the ileum is fixed, i.e., has lost its mesentery, the usually free cecum is likewise fixed and may have the appendix behind it (fixed ileocecal ensemble). Peterson of Sweden (1934) has given the best, most comprehensive and most explicatory anatomic illustrations of this ensemble (ileum terminale fixatum). His work should be read and studied carefully by every prospective abdominal surgeon, for it contains a description and portrayal of all sorts of possible variants in the attachments of the ileocecal junction, the appendix and the ascending colon with associated peritoneal membranes (*Acta Chir Scandinav*, Suppl 32, 37, 1934).

The left or splenic flexure of the colon is the first to be established and in its definitive position may overlie any portion of the left kidney. The more variable and lower hepatic or right flexure is created when the liver, through a marked reduction in its size (partly through loss of hemopoiesis), moves cephalad. The length of the transverse mesocolon varies considerably. Often it is exceedingly long, reaching into the pelvis. It may be very short—so short as to render the operation of a posterior gastrojejunostomy difficult, if not impossible.

The pelvic segment of the sigmoid colon retains its mesentery (pelvic meso-

enlarged sufficiently to allow room for the expanded gut mass the small intestine is suddenly pulled back into the abdominal cavity through the umbilical ring[2] The returned coils of small intestine fall into the right iliac fossa and gradually push the lower portion of the colon (which because of its slower growth never left the body cavity) still more to the left The cranial or cecal end of the colon which did protrude into the umbilical celom is the last section to re enter the body cavity perhaps because of its cecal swelling As it enters it is thrown to the right side under the liver and over the coils of the small intestine thereby completing the dextrorotation of the gut begun at the time of the herniation of the primitive midgut (the first to be looped) into the extra embryonic umbilical celom As the cecum abuts against the right body wall its concavity is directed cephalad and to the right and the terminal ileum enters the colon from the right to the left But after rotation of the cecum (i e after it turns downward) its concavity faces caudally and to the left and the terminal ileum enters the colon from the left to the right as normally the case in the adult (Huntington) With the caudalward bend of the cecum the first anlage of the ascending colon is formed In later stages the cecum descends lower and lower with relative diminution in the size of the liver until it reaches its definite position in the right iliac fossa[3]

Regarding the rate of gut growth Broman (1927) found that at first the large intestine is very long constituting about one half of the gut length Up to the end of the third month however the growth of the small intestine (especially of the iliac coils in the extra embryonic umbilical celom) exceeds that of the large intestine to such an extent that by the end of this period the large intestine measures one eighth of the entire gut length Subsequently the large intestine takes on a faster rate of growth attaining at the eighth month about one sixth of the length of the entire gut this being the approximate proportion in the adult body

[2] Cause for the sudden return of the gut is unknown According to Broman (1927) reposition of the gut in the body cavity is caused by the great *enlargement of the liver During the first half of* the third month its ventrocaudal border becomes shifted to the level of the pelvis on both sides The gut loop is thereby pressed caudalward by the liver so much so as to overcome the forces in the navel hernia which prevent reposition *A dorsoventral* enlargement of the liver likewise assists in the process of reposition

[3] Richard Hunter of Queen's University Belfast (1928) after a study of a series of human fetuses and adult cadavers concluded that the common opinion that the ascending colon is formed as the cecum descends is erroneous In a fetus of 6 cm length after the intestines have been withdrawn from the umbilical cord the ileocecal junction is not high up in the abdominal cavity but along with the liver is placed well down close to the level of the highest point of the iliac crest After its withdrawal from the umbilical celom the developing colon does not pass from right to the left as commonly taught but instead passes obliquely from the right iliac crest below the lower pole of the right kidney upward and to the left to the splenic flexure (13.5 cm embryo) As the colon in its ascent to the left crosses the second portion of the duodenum it forms an adhesion with it This adhesion is an important landmark for the curved segment of the colon between it and the cecum anlage form the whole of the ascending colon and *that part of the transverse colon situated* between the adhesion point and the hepatic flexure The bulge on the anterior wall of the cecum gives the appearance of a downward movement but this is more apparent than real being simply the *flowing* over of an irregularly developing sac the cecum fixed by its ileocecal junction Though a rotation of the ascending colon from left to right its mesocolon becomes fused with the posterior abdominal wall If this rotation does not occur a mesocolon (i e mobile ascending colon) is formed Proof that the ascending colon actually rotates to the right is forthcoming from the direction of the longitudinal taenia in the adult body for here the ventral band of the longitudinal muscle fibers in the transverse colon curves around at the hepatic flexure and appears on the right dorsolateral surface of the ascending colon while the ventral longitudinal band on the ascending colon bends below the hepatic flexure and appears on the infradorsal surface of the transverse colon

In criticism of Hunter's contention it may be stated that very frequently the author has seen the ileocecal junction lying high up in the abdominal cavity in newborn babies and in fetuses of different ages

abdomen—i e organs which normally are found on the right side are found on the left side and vice versa Synonymous terms for this condition are heterotaxy lateral inversion of the viscera and more commonly transposition of the viscera or mirror image of the normal position Situs inversus partialis denotes a condition in which only the viscera of the thorax or those of the abdomen are transposed laterally Contralateral rotation of the viscera can be distinguished readily in all cases by x ray studies from conditions showing arrested or nonrotation of the colon or from conditions in which *the duodenum is not in a retroperitoneal position* the gut having a common mesentery

Comprising a third group are instances in which there is a dextral rotation of certain thoracic viscera (dextrocardia) with partial subdiaphragmatic situs inversus (liver reversed stomach on left side Walls 1912) The situs inversus condition may be anatomically perfect—i e the transposed organs are normal the blood vessels show standard textbook types of pattern (Fig 91) and the nerve supply remains the same although reversed Often however the situs inversus condition involves marked and multiple deformities of both the skeleton and the viscera as recently reported by Shryock Janzen and Barnard (1942) in a case of sympus dipus

From data in the literature it is exceedingly difficult to determine the incidence of situs inversus In a communication to Wood and Blalock Balfour (1940) states that 51 cases were observed at the Mayo Clinic over a period of 21 years Adams and Churchill reported 23 cases in 232 112 at the Massachusetts General Hospital Le Wald (1925) reported 1 case in 5 000 autopsies Rosler (1930) 3 cases in 22 102 autopsies Newman (1940) reported 1 case in 10 000 dissections at the Columbia University College of Physicians and Surgeons The case encountered at the Daniel Baugh Institute of Anatomy of Jefferson Medical College and studied by Verano was according to J Parsons Schaeffer its Director at the time the first he encountered in 5 000 dissections

With respect to the cause and the significance of transposition of viscera both the genetic theory popularized by Cockayne (1938) and the developmental arrest theory advanced by Newman (1940) seem to be founded on such sound statistical and experimental evidence as to favor the view of Adams and Churchill (1937) to wit that some cases of situs inversus may have resulted from a genetic factor (endogenous) while others were dependent on influences that became active following fertilization (exogenous) For further details on the etiology of situs inversus the reader is referred to the cited literature

Mesenteries which normally become fused to the posterior abdominal wall may fail to do so giving rise to a mobile ascending or descending colon or to a duodenum with a mesentery Obstruction of the third part of the duodenum by the superior mesenteric artery has been found to be associated with a mobile ascending colon (Bloodgood 1907)

In a well illustrated radiographic study published in the *British Journal of Surgery* (1923) McConnell and Hardman of Trinity College Dublin have shown that *the ascending colon is the only structure that reacts abnormally to posture pain being associated with a definite position or deformity of the ascending colon in over 90 per cent of cases If position be altered or deformity be removed surgically, pain disappears* Faulty fixation of the ascending colon results in (1) variation in its actual form (angularity or collapsed types) (2) excessive tension on the structures to which it is attached Traction of the mobile ascending colon may produce acute angulation of the duodenum and

colon) whereby normally the gut is brought back to the midline at the third sacral vertebra This mesentery may be extremely long carrying the sigmoid colon under the splenic flexure or to a region near the appendix The rectum not only loses its mesorectum but also in its lower one third is completely devoid of a peritoneal covering

Rotation of the gut when complete amounts to 270° It may be arrested at any level Frequently the arrest of the cecal journey takes place under the liver giving rise to the subhepatic appendix the latter being dorsal to a fixed cecum The appendix may be at midlevel of the ascending colon projecting upward behind the latter for 3 to 5 inches caught there in the descent of the cecum like the rope of a sled sliding down hill In its return from the umbilical celom the gut may not rotate at all placing the jejunum and the ileum to the right and the colon to the left Rotation of the midgut and the stomach may be the reverse of normal thus producing a transposition of the gut segments the right being where the left should be and vice versa This condition is known as the situs viscerum inversus or mirror image transposition of the organs as shown in one of the author's illustrations (Fig 94) Factors concerned in gut rotation were presented by Mall (1898) Fraser and Robbins (1939) and more recently by Gardner of Duke University (1950) who not only presented a clear cut illustration of the 3 stages of midgut rotation but also gave an extended account of the varieties of malrotation of the gut Five cases of anomalies of intestinal rotation were reported by Dott (1923) and 19 by McIntosh and Donovan (1939)

The problem of situs inversus viscerum or mirror image of organs cannot for obvious reasons be discussed fully in this atlas However to afford access to the pertaining literature and to the nature of this important topic, the author will record items compiled by Dr Verano during his investigations of a case (a male Negro 45 years old) encountered at the Daniel Baugh Institute of Anatomy while he held a Ross V Patterson fellowship at the Jefferson Medical College (1941–1942) the author having helped him in orientation and exposition of his problem

The literature on situs inversus viscerum has been reviewed adequately by Cleveland (1926) who found 400 cases reported in the literature by Larson (1938) who found 75 additional reported cases and by Wood and Blalock (1940) who reported 1 case More recent are the reports of Walls (1942) on a case of dextrocardia and of Shryock Janzen and Barnard (1942) on a case of sympus dipus with complete transposition of viscera in a 5 weeks premature fetus

Transposition of viscera has been recognized since the time of Aristotle who recorded 2 instances of transposed organs in animals In 1600 Fabricius described a case of reversed liver and spleen in man while Servius (1615) described a case of transposition of viscera In 1824 Kuchenmeister reported a case in a living person and in 1897 Velsemeyer demonstrated a case roentgenographically Modes of experimental production of situs inversus were obtained by Spemann (1906) Pressler (1911) and Vogt (1921) Other important contributions on situs inversus are those of Morrill (1919) Stockard (1921) Sherk (1922) Le Wald (1925) Rosler (1930) Adams and Churchill (1937), Cockayne (1938) Larson (1938), Balfour (1940) Newman (1940) and Walls (1942)

Anatomically considered the following categorization should be borne in mind Situs inversus viscerum totalis usually is interpreted as a condition in which there is a lateral transposition of the viscera of both the thorax and the

geal diverticulectomy as proved in 204 consecutive cases because of the absence of mediastinitis a mortality of 2.5 per cent in an age group averaging 60 years and with only one recurrence The incidence of these pharyngeal diverticula among total operations at Jefferson Hospital was 1 in 800 Dr Clerf the bronchoscopist having usually assisted Dr Shallow surgically in these cases

Baldwin of Cornell University (1911) found 15 duodenal diverticula in 105 duodena and classified them into true or false types—in the former all coats of the intestinal wall were present in the latter the muscularis was wanting Sterling (1919) observed 4 diverticula of the terminal or intrapapillary (pars intestinalis) of the common bile duct in 70 anatomic dissections Two of the diverticula contained stones and showed evidence of pancreatitis Duodenal diverticula occur most frequently at or near the major duodenal papilla but they have been observed at the pylorus and on the cranial surface of the transverse duodenum Situated for the most part at the left or concave side of the duodenum the diverticula project fingerlike directly into the pancreas lie behind it or become lodged caudad to the head of the pancreas The bile duct the pancreatic duct or both may open into the bladderlike diverticulum When a diverticulum develops at the site of the minor duodenal papilla the duct of Santorini may open into it

Intussusception or the invagination of an upper segment of the gut into a lower segment (small intestine into small intestine small intestine into large intestine as predominantly occurring in infants and children [Drugas and Schiff 1954]) are common causes of obstruction Intussusception of the appendices epiploicae may cause intestinal obstruction of the sigmoid colon In other regions unusually long and large epiploic appendages may cause obstruction by their adhesion to a loop of bowel or to the vermiform appendix forming an obstructive band which through torsion may become sufficiently tight to cut off the blood supply with resultant gangrene Loop after loop of small intestine may herniate internally into the retroperitoneal space a common site of opening for such internal herniation being the paraduodenal fossa of Landzert made by the union of the superior and the inferior duodenojejunal peritoneal folds Volvulus or a twisting of the gut may occur anywhere that of the sigmoid colon and the cecum being common (Jacobsen Graham Gardiner Desforges and Wilson 1953)

The topic of retromesocolonic hernia is fully discussed and illustrated by Burnham of Salt Lake City Utah in the *Journal of the International College of Surgeons* (1953) Herniation of the bowel into intra abdominal sacs formed of mesocolon that usually are fused to the posterior parietal peritoneum have been termed retroperitoneal paraduodenal retromesocolic and intra abdominal hernia Very few of these hernias have been diagnosed preoperatively most of them having been detected incidentally at operation at autopsy or during dissection In an adult male a case was encountered by the author in the dissecting rooms of the Daniel Baugh Institute of Anatomy The entire small bowel and a part of the large intestine were contained in a mesocolonic sac the opening of which was at the paraduodenal fossa The entire herniated gut section was removed readily from the sac as no adhesions were present In Burnham's case the mesocolic sac contained all of the small bowel from the second part of the duodenum the cecum and the ascending colon and constituted a symptomless anomaly

According to Hansman and Morton (1939) reports on intra abdominal her

tension on the superior mesenteric artery these being factors in duodenal obstruction that at times may be correlated with anterior convexity of the lumbar spine Surgical diagnosis of abdominal pain is explained by Bates (1941) and Carnett (1934) both of Philadelphia

Duplications of the gut may occur from mouth to anus being most frequent in the small intestine as the jejunum (Johnston 1954) Dohn and Povlsen of Sweden (1951) found 315 reported cases of intra abdominal duplications While congenital atresias may occur in any part of the gut they are prone to appear in the duodenum at the ileocecal junction and in and about the rectum—the latter in some instances ending blindly at a considerable distance from the anus Congenital pyloric stenosis the cause of which is still in doubt has at times a familial history and is more frequent in the male than in the female

Diverticula of the pharynx (pulsion type) the esophagus the duodenum the cecum and the sigmoid colon are of common occurrence According to Shallow Samuel D Gross Professor of Surgery at Jefferson Medical College (1936) —(as first reported in a paper read before the Philadelphia County Medical Society March 22 1932 in honor of Dr John Chalmers DaCosta of Jefferson Medical College)—*a clear distinction must be made between esophageal and pharyngeal diverticula* The former arise either opposite the bifurcation of the trachea or at the lower end of the esophagus from periesophageal inflammations and are therefore never pulsion in origin the latter actually arise in the pharynx just above the beginning of the esophagus and accordingly are pulsion diverticula herniation of the sac of pharyngeal mucosa and submucosa being effected either through or above the cricopharyngeus (string) muscle (This muscle comprises the lowermost muscle fibers of the inferior constrictor that arise from the cricoid cartilage) After an experience with 79 cases of pharyngeal diverticula Shallow maintains that this type of diverticulum may arise from any part of the pharynx that is perforated by a branch of the inferior thyroid artery The true pulsion diverticula of the pharynx that he encountered arose in 3 areas (1) Most frequently from the commonly described area above the cricopharyngeus (sling) muscle either on the left or the right they being more frequent on the left only 4 of the 79 being on the right (2) In the Killian Jamieson area on the posterolateral wall of the pharynx below the cricopharyngeus and above the circular muscle fibers of the esophagus It is through this weak area that the inferior laryngeal nerve a branch of the inferior thyroid artery and a lymph bundle pass (35 per cent) (3) Through the lower part of the inferior constrictor muscle where another branch of the inferior thyroid artery passes through the wall this type being the least frequent Shallow devised a one stage operative technic (as opposed to the two stage procedure) for the removal of the sac 74 of his series having made a complete recovery Further data on pharyngeal diverticula are to be found in the articles published by Wilkie and Hartley (1922) Raven (1933) Lahey (1933 1946) Moersch and Judd (1934) Eliason Tucker and Thigpen (1937) Hershey (1941) Bortone (1945) Morley (1945) Furstenberg (1947) and King (1947) The first observations of pharyngeal diverticula were made by Ludlow (1764) Monroe (1811) and Bell (1816) Niehaus according to Shallow was the first to have extirpated the sac in 1884 Joseph Hearn of Jefferson Medical College being the first (1896) to have extirpated one of these sacs in the United States

In his paper of 1949 Shallow showed the safety and the effectiveness of his combined one stage method of pharyn

arteries supplying the small intestine and the colon are the reverse of what they were primitively, i.e., after rotation, branches to the small intestine arise from the convex left side of the superior mesenteric artery, while branches to the colon arise from the right concave side. (3) The transverse mesocolon, after crossing and becoming fixed to the second part of the duodenum (pars fixa), attains a new attachment to the caudal anterior surface of the body and the tail of the pancreas (pars libera), thereby affording new and additional routes of blood supply from the splenic rami coursing caudally through the pancreas (posterior epiploic arteries). (4) The proximal end of the horseshoe-shaped duodenum receives a precarious transitory type of blood supply from branches of the right gastric, the hepatic (through the supraduodenal artery), and the gastroduodenal (through the retroduodenal and the superior pancreaticoduodenal). (5) The distal end of the horseshoe-shaped duodenum crosses the midline and the aorta, allowing the region of the duodenojejunal junction to receive a blood supply not only from jejunal branches from the superior mesenteric but also from branches of the inferior pancreaticoduodenal and the retroduodenal arteries. (6) The body of the pancreas is brought into relation with the course of the splenic artery, thereby allowing the latter to give off several pancreatic rami. (7) The tail of the pancreas becomes fixed to the left suprarenal gland and part of the left kidney and is brought near the hilus of the spleen, where it receives branches from the splenic terminal arteries and from the left gastro-epiploic.

The Spleen and Accessory Spleens

The Spleen

The spleen arises in the fifth week as several delimited hillocks of mesenchymal cells in the left leaflet of the dorsal mesogastrium adjacent to the fundus of the stomach and to the left of the pancreas, the hillocks soon merging into one triangular projecting mass. According to Ono's (1930) investigations of 32 human embryos and fetuses, the splenic anlage at first consists of an aggregate of round mesenchymal cells without a demonstrable participation of blood vessels. As a precursor to capillary development, there appears initially a network of spaces (cavities) formed by splitting of mesenchyme. Ono's reconstruction models show that the most primitive vessels reaching the splenic anlage to become distributed in it are two branches of the venae portae, i.e., mesenteric veins. One runs independently and is primary; the other accompanies an artery and is secondary. Both veins and their branches anastomose frequently, thereby forming a large venous plexus. Ono accordingly shares the opinion of most investigators—viz., that in vertebrates there is no definite dependence of the splenic anlage with the arterial system, for when the venous system is well established the arteries are still incompletely developed. Laguesse (1891) went so far as to call the splenic anlage the "reticulated blind sac of the portal system."

The opposite view (viz., that arterial capillaries appear very early in the splenic anlage) was taken by Mollier (1910), Sabin (1910), and Thiel and Downey (1921). The latter two authors showed that in pig embryos the earliest splenic vessels consist of numerous tiny capillaries which run from the mesenteric artery into the splenic rudiment, where they become distributed in the form of a capillary network, this condition persisting until the open circulation of the adult spleen becomes established. The open circulation sets in before the middle of the embryonic life and is effected through communication between the vascular capillary network and the primitive splenic sinuses.

nations have comprised the following types paraduodenal 53 per cent peri cecal and ileal 13 per cent perimesenteric 8 per cent foramen of Winslow 8 per cent pelvic 7 per cent retrosigmoid 6 per cent miscellaneous 5 per cent Both large and small bowel have been found in the lesser peritoneal sac (omental bursa) Such herniations through the foramen of Winslow need not necessarily be of congenital origin for the herniation may have been caused by a long mesentery or an unfixed ascending colon Burnham cites Lahey s statement that the operative mortality for right paraduodenal hernia is 50 per cent His reported case had a fatal issue

Vitelline Stalk Failure of rotation beyond the first stage and retention of the midgut in the umbilical stalk is known as in omphalocele (a case report by Arnheim 1950 and by Gardner, 1950) By becoming thinner and thinner the vitello intestinal duct normally first loses its entodermal then later its mesodermal connection with the apex of the midgut loop Persistence (2 per cent) of its proximal portion gives rise to a Meckel s diverticulum of the ileum (1 to 8 inches long 6 to 18 inches from the ileocecal junction) Abnormalities of the vitelline stalk comprise (1) a persistent vitelline cord with an umbilical sinus (2) an umbilical appendage with a sinus (3) a vitelline cyst (4) a vitelline fistula (5) a vitelline mesodermal stump attached to the mesentery of the ileum and containing the persistent arteria vitellina which may rupture after birth (6) pancreatic and gastric mucosa tissue aberrantly placed in its walls

In postnatal life a persistent Meckel s diverticulum through growth and torsion may form knots about gut loops causing obstruction and strangulation of the bowel The three types of knot formation described by Treves are (1) the diverticulum forms a ring into which its own free end projects A loop of the gut then enters the ring pushes the club shaped end of the diverticulum before it and so ties the knot (2) the diverticulum may form a simple knot by encircling the pedicle of the intestinal loop, (3) the diverticulum may involve two loops of the bowel one above, the other below its origin One loop enters the knot by primary rotation the other loop is caught in a simple knot On many occasions a Meckel s diverticulum becomes united with the mesentery of an adjoining gut forming a bridge under which a gut loop moves and becomes strangulated

Regarding the vermiform appendix it is beyond the purpose and the scope of the author in this atlas to give a review of its variational anatomy and topography, its relations to the peritoneal fossae and the ligamentous bands and its developmental anomalies Suffice it to say that because of the manifold points at which the gut may be arrested during rotation and the varied manner in which the sections of the gut become attached to the posterior abdominal wall the appendix may assume almost any position below the transverse mesocolon Normally attached to a mesentery (mesenteriolum) it hangs freely in the pelvic cavity Variational positions comprise pre iliac postiliac supra iliac or infra iliac retrocecal (free or fixed in the latter case being retroperitoneal) retrocolic (behind ascending colon [subhepatic appendix] or overlying the right ureter) or entirely on the left side as is the case in situs inversus For appendix see page 23

The main effects of the gut rotation as far as the blood supply of the regional organs is concerned are the following (1) The transverse colon is brought in front of the superior mesenteric artery while the horizontal part of the third part of the duodenum and a part of the pancreas (the uncinate process) is placed behind it (2) The ascending and the descending colon lie respectively to the right and the left of the superior mesenteric artery The sites of origin of the

arteries supplying the small intestine and the colon are the reverse of what they were primitively, i.e., after rotation, branches to the small intestine arise from the convex left side of the superior mesenteric artery, while branches to the colon arise from the right concave side. (3) The transverse mesocolon, after crossing and becoming fixed to the second part of the duodenum (pars fixa), attains a new attachment to the caudal anterior surface of the body and the tail of the pancreas (pars libera), thereby affording new and additional routes of blood supply from the splenic rami coursing caudally through the pancreas (posterior epiploic arteries). (4) The proximal end of the horseshoe-shaped duodenum receives a precarious transitory type of blood supply from branches of the right gastric, the hepatic (through the supraduodenal artery), and the gastroduodenal (through the retroduodenal and the superior pancreaticoduodenal). (5) The distal end of the horseshoe-shaped duodenum crosses the midline and the aorta, allowing the region of the duodenojejunal junction to receive a blood supply not only from jejunal branches from the superior mesenteric but also from branches of the inferior pancreaticoduodenal and the retroduodenal arteries. (6) The body of the pancreas is brought into relation with the course of the splenic artery, thereby allowing the latter to give off several pancreatic rami. (7) The tail of the pancreas becomes fixed to the left suprarenal gland and part of the left kidney and is brought near the hilus of the spleen, where it receives branches from the splenic terminal arteries and from the left gastro-epiploic.

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However Ono found absolutely no evidence for a closed circulation in any stage of the development of the human spleen for in all instances arterial capillaries were separated from the venous plexus by mesenchymal layers The splenic artery according to Ono does not pertain to the original splenic anlage but grows in later His reconstruction models show that the splenic artery from the celiac accompanied by secondary splenic veins reaches the hilus where it connects with the left gastric Branches are given off by the splenic artery 4 of which may be followed into the spleen For a short distance the caliber of the arteries is thick because of their mesenchymal coats then the arteries suddenly become thick capillaries which branch forklike and ride on branches of the veins The arterial endings show no relation to venous plexuses but become lost in the splenic mesenchyme

With the beginning of the third month according to Ono the splenic anlage undergoes a transformation period during which the characteristic structural elements of the spleen are formed (pulp reticulum venous sinuses arterial ellipsoids lymphoid tissue) In the neighborhood of the venous plexuses the reticulum formed by the mesenchyme changes into lacunae which are the beginning of the true venous sinuses Neoformation of these sinuses is coextensive with hemopoiesis (granulopoiesis and erythropoiesis) which is maximal at the fifth month but becomes insignificant during the sixth month (Thiel and Downey) The stem cells are hemocytoblasts derived from fixed mesenchymal cells Lymphoid sheaths appear at the beginning of the fifth month as aggregations of lymphocytes around certain parts of the artery which are permeable Malpighian corpuscles devoid of germinal centers make their appearance in the lymphoid sheaths by the end of the fifth month attain their outer and inner vascular networks by the end of the seventh month and become fully developed shortly before birth

After sacculation of the dorsal mesentery the triangular shaped primitive splenic anlage gradually becomes separated as an independent organ from the omental bursal wall remaining attached to the latter only at the hilus by ligaments As the spleen grows in thickness it becomes stretched longitudinally loses its triangular form and develops notches (furrows) on its outer surface especially in the caudal portion of the organ where they may form isolated (accessory) spleens The characteristic morphology of the adult spleen is attained at the third month

Little is known regarding the embryonic development of the connective tissue framework of the human spleen A clear cut demonstration of the architecture of the supporting framework of the adult spleen was worked out by G A Bennett Professor of Anatomy and Dean of Jefferson Medical College in a plastic reconstruction wax model which he made at the University of Munich from sections (7 5µ) of a piece of spleen taken from a 36 year old male Following the description of this model by Hartmann and Bennett (1927) the supporting framework of the spleen is developed in the form of strong round or flattened strands—i e widely perforated membranes which are oriented in such fashion as to constitute individual irregular chambers the interior of which contain the splenic parenchyma (arterioles with lymphoid sheaths venous sinuses and pulp reticulum) By means of these septumlike fenestrated partitions all chambers communicate with one another the chambers being comparable with the lobules of the spleen as described by Mall of Johns Hopkins University (1898)

Topographically considered the spleen is not secondarily retroperitoneal like the pancreas nor primarily retroperitoneal like the kidney. It is intraperitoneal like the stomach and therefore is freely movable—so much so that it may be grasped in the hand by its pedicle and lifted away from the body wall. It has a complete peritoneal covering except at the hilus and at its point of contact with the pancreas when such relation is present. Duplications of the dorsal mesogastrium form the two main ligaments (pedicle) of the spleen: ventrally, the *anterior omental layer forms the gastrolienal ligament* by which the spleen remains attached to the greater curvature of the stomach and through which courses the left gastroepiploic artery; dorsally, the *posterior omental layer* gives rise to the phrenicolienal (pancreaticolienal) ligament by which the spleen becomes attached to the diaphragm and through which course the tail of the pancreas, the splenic artery, and the splenic vein. The spleen, though freely movable, becomes fixed through pressure of the surrounding organs and through the phrenicocolic ligament, a part of the great omentum that extends from the left colic flexure to the under surface of the diaphragm. This ligament forms a horizontal shelf on which rests the inferior pole of the spleen. It is often molded into a sac that opens cranialward. Downward movement of the sac allows for displacement of the spleen. Frequently a splenocolic ligament produced by adhesion of the dorsal mesogastrium (great omentum) affords additional attachment. Occasionally the renal surface of the spleen becomes fused with the dorsal body wall through loss of the phrenicolienal ligament.

The morphology of the spleen is characterized by the fact that in the living body the spleen shows decided variations in size (amount of blood content) and form (Barcroft and Stephens 1936, Knisely 1936, Peck and Hoerr 1951).

It was known by Hippocrates that "eodem die lienem magnum et iterum parvum fiere" (cit. Henschen and Reissinger 1928). Furthermore, when the stomach is contracted and the colon distended, the spleen is tetrahedral, whereas when the stomach is filled and the colon empty, the form of the spleen is that of an orange segment. Surgical troubles of the spleen are discussed by Reid of Northwestern University (1954).

In a study of 100 cadaver spleens (1942) the author observed that 44 per cent were orange-segmentlike, 42 per cent tetrahedral and 14 per cent triangular. Measurements of the splenic surfaces gave the following average figures: gastric surface, 4 cm.; renal surface, 3 cm.; diaphragmatic surface: (a) length, 11 cm., (b) width, 7 cm.; colic surface, 2 to 5 cm. The intermediate border varied from 4 to 13 mm., average 8 mm.

Collectively considered, one may distinguish two types of spleens: (1) a compact type with narrow hilus and even borders and (2) a distributed type with distributed hilus, notched anterior border, a thumblike lobe at the inferior pole and a tubercle at the upper pole. The types give rise, respectively, to two types of the splenic artery: (1) Magistral type (30 per cent) in which the splenic trunk *is long, terminal division occurs near the* hilus, branches are few, large and enter about one third to one fourth of the medial surface. Superior polar arteries are absent or arise from the superior terminal. The left gastroepiploic often arises from the inferior terminal. (2) Distributed type (70 per cent) in which the splenic trunk is short, lienal branching occurs early, anywhere from the celiac artery to the hilus, branches are more numerous, smaller in caliber and enter three fourths of the medial surface, at times being distributed to the

entire medial surface in successively placed frontal planes 3 to 20 in number Polar arteries are frequent distributed to the upper and the lower poles The left gastro epiploic as a rule arises from the splenic trunk

The more extensive observations of the author on the morphology of the spleen and on the variational patterns of the splenic artery and its branches will be found in Chapter 8 *The variational* patterns of the splenic vein have been recorded and illustrated by Douglass *Baggenstoss* and Hollinshead (1950) *and the surgical dangers thereof are dis*cussed on page 202

Accessory Spleens

Instances of a *double spleen or of a* congenital absence of the spleen occur very rarely the anomaly and the defect were never seen by the author over a period of 1 *500* dissections Small accessory spleens however are well known and common structures being less frequent in the adult (10 per cent Halpert and Eaton 1951)[4] than in infants (25 per *cent* Jolly) They *may be lo*cated at the anterior and the posterior margins of the spleen at the upper pole or at the hilus or they may be peduncu*lated to the gastric surface Commonly* they are found in the gastrolienal the gastrocolic and the pancreaticolienal ligaments in the upper part of the great omentum and *in the lower surface of* the transverse colon

[4] The preliminary report of Halpert and Eaton *(1951) on accessory spleens is as follows* The necropsy records of 600 patients in whom special search was made to locate accessory spleens were reviewed Accessory spleens were encountered and microscopically verified in 62 instances Their sizes ranged from 0 2 to 3 cm In 52 instances one accessory spleen was present in 6 there were two in 3 there were three and in 1 instance there were several accessory spleens with absence of a spleen *proper There were 23 among 205 patients in the* first decade of life 3 among 14 in the second 3 among 37 in the third 6 among *44 in the fourth* among 51 in the fifth 10 among 129 in the sixth 6 among 71 in the seventh and 6 among 49 in the eighth decade of life The oldest patient having an accessory spleen was 75 years old It is concluded that the overall incidence of 10 per cent is a reliable estimate of the occurrence of accessory spleens (*Anat Rec* 109 111 1951)

The majority of accessory spleens are round or oval and about the size of a large pea (1 × 1 cm) When situated at the hilus *the splenic tissue* usually forms a fossa for them (Fig 133) The largest accessory spleen observed in 100 bodies measured 2 × 3 5 cm (Fig 123) and was found in *the phrenicogastric* ligament at the upper pole of the spleen Its blood supply came from an independent branch of the splenic trunk The maximal number of accessory *spleens observed* was 4 *they being* found in the gastrosplenic ligament their size varying from 5 to 10 mm (Fig 138)

Phylogenetically considered accessory *spleens may be grouped into the follow*ing types (1) Lienes succenturiati (Haberer 1901) which most probably represent detached or split off portions of *the spleen found at the anterior and the posterior margins of the spleen They* may be entirely severed or attached by a small stalk (pedunculated) to the gastric surface of the spleen or hang from the *lower pole* as a thumblike lobe (Figs 131 113) (2) Lienes accessorii found as isolated and independent splenic tissue usually at some distance from *the spleen (Figs* 116 126 129) Formation of the first group is secondary and is due to deep incentation fissuration and lobulation i e retention of the original *embryonic mode of splenogenesis* via multiple mesenchymal splenic hillocks Formation of the second group is primary i e constitutes excessive *spleno*genesis and is due to the inherent capacity on the part of the entire dorsal mesogastrium to form splenic anlagen Since in *lower* vertebrates *the spleen may* be situated at the stomach the pylorus the foregut the midgut and the hindgut (turtle) (i e anywhere in the dorsal *mesogastrium) it is in conformity* with the evolutionary principles that accessory

spleens occur in man in sites remote from the spleen in some instances even in the pancreas as microscopic islands (Haberer 1901 Klemperer 1930) and in the appendix epiploica of the descending colon (Schilling)

It is interesting to note that in infants and children up to the fourteenth year accessory spleens are more common than in adults Thus in an autopsy of 80 infants Jolly (1895) reported an incidence of 25 per cent The presence of accessory spleens in the adult indicates that a large quota of the accessory spleens in the infant are not transitory structures i e undergo atrophy but actually persist as functional entities For discussion of the neoformation of accessory spleens after splenectomy (Tizzoni 1881) the reader is referred to the paper by Meyer of Stanford University (1911) in which this power is doubted the structures being considered as hemal nodes

The Mesenteric Trunk and Its Contents

In speaking of the root of the mesentery one usually thinks of the root of the small intestine (radix of the mesentery) suspended from the dorsal body wall and extending from the left side of the second lumbar vertebra to the right iliac fossa However this is merely the secondarily acquired line of attachment of the mesentery of the small intestine The main trunk (pedicle) of the mesentery (truncus mesentericus Gekrosstiel) according to Pernkopf (whose concept is closely followed here) is constituted by the dorsal mesoduodenum and its pancreatic mass as it lies fixed (fused) to the posterior abdominal wall Accordingly all mesenteries adjacent to the primitive mesoduodenum (dorsal mesogastrium great omentum common mesentery) no longer arise from the midline of the dorsal body wall but become attached to the left side of the dorsal mesoduodenum When through rotation of the gut the ventral mesoduodenum is shifted to the right a derivative of it (viz the hepatoduodenal ligament) likewise arises from the mesenteric trunk

After the duodenum has shifted to the right and the duodenojejunal flexure has shifted to the left as a result of gastroduodenal rotation the massively enlarged pancreas laden mesoduodenum becomes fused with the dorsal body wall and as such acts as the trunk (pedicle) of the mesentery through which all vessels and nerves supplying the pertaining and attached mesenteries must travel

The main mass of the trunk of the mesentery lies at the level of the first lumbar vertebra more to the right than to the left Through connective tissue it is intimately related with the hilus of the right kidney and with the right renal vessels To the right the mesenteric trunk is delimited by the U shaped duodenum in the concavity of which lies the head of the pancreas Ventrally the trunk is covered by a serosa layer which poses as parietal peritoneum but below the root of the great omentum actually is derived from the serosa of the fused transverse mesocolon while above the root of the great omentum it becomes continuous with the serosa of the fused dorsal mesogastrium and as such participates in the formation of the back wall of the omental bursa

Developmentally considered therefore two mesenteries arise from the anterior surface of the mesenteric trunk (1) The root line of the attachment of the great omentum (transverse mesocolon) which begins at the head of the pancreas then follows the caudal border of the pancreas to the left where it becomes continuous with the root line of the dorsal mesogastrium Actually this root line of the great omentum arose through fusion of the dorsal mesogastrium with the transverse mesocolon and as such constitutes the back free wall of the great omentum (2) The radix of

the mesentery of the small intestine which starts at the incisura pancreatis and proceeding in a caudal direction crosses the infracolic portion of the duodenum obliquely

To the right the anterior surface of the trunk of the mesentery is partly devoid of a serosa (peritoneal) layer viz to the extent in which the transverse colon becomes fused with the head of the pancreas and the descending duodenum Cranially from the trunk of the mesentery, arises the pedicle of the liver (made by the hepatoduodenal ligament) and two arching peritoneal folds (a) to the right the plica hepatopancreatica which arises from the head of the pancreas contains the common hepatic artery and unites with the hepatic pedicle (hepatoduodenal ligament) (b) to the left the plica gastropancreatica which likewise arises from the head of the pancreas but contains the left gastric artery and the coronary vein carrying these to the cardiac end of the stomach Cranially the mesenteric trunk becomes continuous with the fused dorsal mesogastrium which forms the back wall of the omental bursa

The contents of the trunk of the mesentery are intimately related with the inferior vena cava the aorta and especially the left renal vein The contents comprise

1 The head of the pancreas It is attached to the ring shaped duodenum and through the development of the isthmus and a tuber omentale (which overlies the vertebral column) extends to the left of the body this lying behind the back wall of the omental bursa

2 The stems of the large gut arteries which belong to the respective mesenteries arising from the mesenteric trunk and which therefore must of necessity pass through it (a) the stem of the celiac artery enters the trunk from above but its branches soon leave it the hepatic artery via the plica hepatopancreatica the left gastric via the plica gastropancreatica and the lienal a bit later via the plica lienalis along the *upper border of the pancreas* Only a branch of the hepatic viz the superior pancreaticoduodenal, via the gastroduodenal actually passes through the trunk to wit between the duodenum and the head of the pancreas (b) the superior mesenteric artery courses through the trunk obliquely It descends behind the pancreatic isthmus and in front of the left renal vein and reaches the radix of the small intestine leaving only a small branch in the mesenteric trunk viz the inferior pancreaticoduodenal artery

3 The veins of the trunk These anastomose meagerly with those of the dorsal body wall and do not enter the inferior vena cava but join the portal vein formed in the mesenteric trunk behind the isthmus (neck) of the pancreas by the union of the superior mesenteric and the splenic veins The portal vein enters the trunk to the right of the superior mesenteric artery anterior to the inferior vena cava In the trunk the superior mesenteric vein lies to the right and ventral to the superior mesentery artery The splenic vein crosses the superior mesenteric artery shortly after the latter s origin from the aorta All these vessels lie anterior to the left renal vein which as it passes between these vessels and the aorta may become severely compressed causing disturbance of blood flow

4 The lymph vessels which become confluent in the mesenteric trunk These comprise lymphatics from the liver the stomach the spleen the pancreas the entire small intestine and part of the large intestine (ascending and transverse colon) After passing through regional lymph nodes these lymphatics as the major intestinal trunks bore through the trunk of the mesentery in the direction of the celiac and the superior mesenteric arteries and finally reach the retroperitoneally placed thoracic duct

(above or below the left renal vein). The lymph nodes which actually lie in the trunk of the mesentery are the cranial pancreatic group found above the head of the pancreas, the duodenal group lying between the head of the pancreas and the duodenum, and the caudal pancreatic group which lies below the head of the pancreas at the radix of the mesentery of the small intestine near the incisura pancreatis.

5. The nerves which accompany the celiac and the superior mesenteric arteries and which arise from the celiac and the superior mesenteric ganglions, the latter reaching into the trunk.

6. The common bile duct, which enters the mesenteric trunk via the hepatoduodenal ligament and transgresses the trunk through its retro (para) duodenal portion.

7. Connective tissue. It participates in the formation of the mesenteric trunk dorsally by effecting fusion of the trunk with the dorsal body wall and to the left becomes continuous with the connective tissue of the back wall of the great omentum. It contains bundles of smooth muscle fibers which proceed from the regional vessels. They reach the ascending duodenum and the duodenal flexure along the course of the superior mesentery artery and act as a suspensory ligament (Treitz) of the duodenojejunal flexure.

The Pancreas and Its Retroperitoneal Displacement

The diversity of the blood supply of the pancreas and the peculiarities of its duct system can be understood more readily when the embryologic development of the organ is considered. In very early embryos (2 to 4 mm stage) the pancreas develops from two outgrowths (outpouchings) of the entodermal wall of the primitive duodenal gut, respectively known as the ventral and the dorsal pancreas. This fact was first recorded in man by Phisalix in a 10 mm embryo in 1888. The dorsal pancreas (upper proximal and first outpouching) arises from the back or dorsal wall of the primitive duodenum. It grows into the dorsal mesogastrium and gives rise to the adult neck, body, tail and upper part of the head of the pancreas. The proximal part of its duct persists as the accessory duct of Santorini (1775). The portion of the dorsal mesogastrium into which the dorsal pancreas grows becomes the posterior wall of the omental bursa after its fusion with the dorsal body wall.

The ventral pancreas (lower distal entodermal growth) is smaller and sometimes paired, the left half disappearing very early. It arises from the floor or the anterior wall of the primitive duodenum at a somewhat lower level than the dorsal pancreas in association with the rudiment of the common bile duct and that of the liver. As a rounded protuberance it is lodged in the inferior angle made by the hepatic diverticulum and intestine or on the diverticulum itself (Bremer). Initially the ventral pancreas grows into the ventral mesogastrium along with the much faster growing hepatic diverticulum, of which it seems to be but a caudal appendage. In its development the ventral pancreatic duct grows away from the duodenum and eventually springs from the posterior wall of the common bile duct (Thyng 1908), which meanwhile has likewise increased in length. Because of an unequal growth of the duodenal wall the ventral pancreas soon turns to the right and dorsally and then grows into the dorsal mesogastrium where it fuses with the 4 to 5 times larger dorsal pancreas, which, because of the caudal shift of the stomach, has moved caudad to meet it. The ventral pancreas gives rise to the adult lower portion of the head and to more or less of the uncinate process, and its duct persists as the main pancreatic duct of Wirsung (1642). Junc

tion of the two original ducts is effected by a single anastomosis to form the definitive duct (Lewis 1912)

During early development both the dorsal and the ventral pancreatic diverticula or buds turn to the right side of the foregut eventually coming in contact and fusing at the point of outgrowth of the ventral pancreas Due to the unequal growth of the wall of the duodenum the second part of the duodenum itself undergoes partial rotation on its longitudinal axis In this rotation, the head of the pancreas is carried behind the portal vein The duct of the dorsal pancreas originally posterior and higher is shifted to the front where its persists as the accessory duct of Santorini opening into the duodenum directly The duct of the ventral pancreas originally anterior and lower is shifted backward to the concave border of the duodenum where it becomes the main pancreatic duct of Wirsung which later becomes joined with the duct present in the body and the tail and which was contributed by the dorsal pancreas

Since the rudiment of the ventral pancreas is associated with that of the common bile duct the backward shift of the ventral pancreas to the concave side of the duodenum causes the following relations (1) ascent of the common bile duct behind the head of the pancreas behind the first part of the duodenum and behind the accessory pancreatic duct (2) a conjoined bile and pancreatic duct situated on the concave side of the duodenum and which opens on the medial side of the descending duodenum via the major duodenal papilla situated 3 inches from the pylorus (3) an independent duodenal opening for the accessory pancreatic duct via the minor duodenal papilla situated 2 cm above and to the left of the major duodenal papilla (4) a common blood supply for the head of the pancreas and the duodenal loop made by the anterior and the posterior pancreaticoduodenal arterial arcades

The retroperitoneal position of the pancreas is effected during the third to the fourth month and is brought about as follows in its primitive sagittal position in the mesoduodenum the pancreas had a right and a left surface a dorsal and a ventral border With the counterclockwise backward and upward rotation of the duodenum the gastroduodenal segment is shifted to the right The mesoduodenum containing the head of the pancreas remains temporarily sagittal whereas the dorsal mesogastrium containing the body and the tail is bulged out toward the left along with the stomach to form the great omental sac The gut shift causes a torsion of the pancreas at its neck so that the primitive right side of the body and the tail now faces ventrad and the primitive left surface faces dorsad—i e toward the dorsal parietal peritoneum with which it subsequently fuses thereby placing the body and the tail in a retroperitoneal position When through a rotational shift to the right the head of the pancreas and its sagittal mesoduodenum becomes frontal its original left surface faces ventrad and its right surface faces dorsad subsequently fusing with the parietal peritoneum Only part of the head of the pancreas is shifted to the left—namely the uncinate process which passes behind the superior mesenteric vessels The definitive pancreas is therefore entirely retroperitoneal The anterior or ventral surface of the body and the tail presents the primitive right surface The head of the pancreas presents the primitive left surface The inferior border is the original sagittal ventral the cephalic is the original sagittal dorsal Of the two primitive pancreaticoduodenal arterial arcades located respectively on the right and the left sides of the mesoduodenum the right becomes hidden when the right side of the mesoduodenum

fuses with the parietal peritoneum remnant of the primitive mesoduodenum being the aponeurosis (fascia) of Treitz (1853) on the back of the head of the pancreas

In the adult the head of the pancreas is usually covered for the most part by the transverse colon which must be detached to see it The body and the tail come to view when the lesser omentum is torn asunder The part of the pancreas which crosses the vertebral column protrudes as the tuber omentale visible through the lesser omentum The inferior (caudal) surface of the pancreas may be seen from the infracolic region i e when the transverse colon is lifted up It lies at the root of its mesentery (transverse mesocolon) In cross section it appears triangular Quantitatively considered the pancreas varies markedly—a major and as yet unsolved problem in anatomy and physiology The tail of the pancreas may or may not reach the spleen On two occasions the author found the tail embedded in the substance of the spleen

Because of its position and its transversely placed long form the pancreas and the duodenal loop associated with it obtain a blood supply from various regional arteries the main trunks being the hepatic the splenic and the superior mesenteric Behind the omental bursa the celiac artery arises from the aorta behind the pancreas and sometimes above it Of its 3 main branches only the left gastric has no relations to the pancreas being covered in its entire course by the secondary peritoneum of the posterior wall of the omental bursa It leaves the body wall to reach the lesser omentum at the cardia via the left gastropancreatic fold

The 3 main arteries (hepatic splenic superior mesenteric) form a peripancreatic arterial circle (Testut) about the pancreas and play an important role in the fixation of the duodenum and the pancreas To the right the duodenal loop is attached to the liver (via the hepatic artery) to the stomach (via the right gastroepiploic) and to the duodenojejunal angle (via the inferior pancreaticoduodenal from the superior mesenteric) To the left pancreatic rami from the splenic artery act as guy ropes suspending the body of the pancreas terminal lienal branches tie the pancreas to the spleen while the transverse pancreatic (inferior pancreatic) artery from the superior mesenteric gives additional support to the duodenojejunal junction

The influence of the extrinsic nerves on the pancreatic blood flow the inhibitory effects of bile on pancreatic secretion and the varied problems connected with the physiology of the pancreas including the pertaining literature are contained in the excellent monograph by Thomas (1950) Professor of Physiology at Jefferson Medical College

The Liver

Its Embryology and that of the Portal and the Hepatic Veins

The liver the gallbladder and the biliary ducts arise from the same entodermal outgrowth of the foregut (ventral wall of the future duodenum) that during the fourth week gives rise to the ventral pancreas As the hepatic diverticulum grows away from the gut tract above the yolk stalk the ventral pancreas and its duct are carried with it so that at a very early stage the ventral pancreas appears to be a bud of the common bile duct with its duct opening into the latter

the actual condition in the adult and patterned thus in the reconstruction model of Thyng (1908) (7 5 mm embryo)

The hepatic diverticulum grows into the septum transversum an unpaired transversely placed shelflike mass of splanchnic mesoderm situated below the

heart above the yolk stalk where it serves as the primitive diaphragm between the thoracic and the abdominal regions The septum extends from the ventral body wall dorsally but does not reach the dorsal wall for dorsal to the septum lie the paired pleural canals which allow communication between the single pericardial cavity and the abdominal part of the primitive celom until such time as the pleural canals become closed off by the pleuroperitoneal folds joining the septum to form the definitive diaphragm

In its earliest stages the septum transversum lies opposite the occipital and the uppermost cervical myotomes at which level it receives its nerve supply (phrenic from the 3rd, 4th and 5th cervical) Through the more rapid forward growth of the body wall the septum moves caudally along with the lower end of the esophagus the stomach and the upper end of the duodenum (descensus viscerum) which ultimately come to lie below the septum whereas primitively they were above it That portion of the septum attached to the gut and containing the developing liver becomes attenuated (stretched out) as the ventral mesentery between the two layers of which the liver attains its final differentiation

The part of the ventral mesentery which extends from the liver to the esophagus the stomach and the first inch of the duodenum becomes the lesser omentum (hepato esophageal hepatogastric and hepatoduodenal ligaments) that proceeding from the liver to the anterior body wall becomes the falciform ligament An area of direct attachment to the septum transversum (diaphragm) however is retained permanently This is the so-called bare area of the adult liver bounded by the coronary ligament and its lateral extensions (triangular ligaments) in a pattern resembling that of a Napoleon hat The round ligament (ligamentum teres) contained in the free margin of the falciform ligament is not a ligament but the obliterated left umbilical vein The ligamentum venosum running from the left branch of the portal vein to the inferior vena cava via a hepatic vein is likewise not a ligament but the obliterated ductus venosus For Wells s findings on the septum transversum see page 28

The mesenchyme of the primitive septum transversum (later ventral mesentery) gives rise to the interstitial connective tissue of the liver lobules (portal canals) to Glisson s capsule and its visceral mesothelial (peritoneal) covering to the connective tissue and to the smooth muscle of the bile ducts

The epithelial hepatic diverticulum grows into the mesenchyme of the septum transversum in a ventral and cephalad direction Its distal portion develops into epithelial cords (trabeculae) which become the glandular lobules of the liver its proximal portion gives rise to the hepatic ducts and the larger intrahepatic bile ducts The gallbladder along with its cystic duct (as will be shown later) is an independent solid epithelial outgrowth from the caudal region of the original hepatic diverticulum

Initially the cords of liver cells as they grow into the mesenchymatous septum transversum form a central mass the so called median lobe From this during the fourth week grow out dorsally two smaller dorsal lobes each of which protrudes into a pleuroperitoneal cavity alongside the mesentery Subsequent growth of the right and the left liver lobes mediates in a large measure the separation of the pleural cavity from the peritoneal cavity by closing the two orifices between them on the one hand and on the other by effecting widespread connections of the liver with the body wall Later (second month) these body wall connections are reduced to ligaments See Wells page 28

The right lobe is larger than the left due to the fact that the anlage of the

vena portae empties on the medial side of the right lobe. As will be shown shortly, at the beginning of the fifth week the left umbilical vein establishes connection with the liver vessels and assumes the nutritional function. Preference of blood supply is not afforded the left lobe, however, for the umbilical blood becomes distributed in the liver through old channels. Since those of the right lobe are larger from the start, the right lobe is favored and accordingly becomes the larger lobe (Broman). Although different in form and in their connections, the definitive main lobes of the liver are recognizable as early as the fourth week. The ventral delimitation between the right and the left lobes is wanting at first but comes to full view with the development of the falciform ligament.

Of the secondary lobes, the caudate is the first to attain its definition—this at the surface of the right dorsal lobe contiguous with the anlage of the lesser omentum. Demarcation of the quadrate lobe on the outer surface of the liver occurs later, due to the fact that the umbilical vein and the gallbladder, which serve as its boundaries, are situated for a considerable time in the depth of the liver and come to the surface only after retrogression of the liver tissue covering them inferiorly.

The size of the liver varies at different developmental periods, its maximal rate of increase occurring during the first half of the third month. After reposition of the herniated midgut loop, the liver continues to increase and at the fourth week begins to excrete bile, a phenomenon associated with the formation of meconium in the gut. The presence of meconium stimulates gut growth to such an extent as to establish a disproportion between the abdominal space and its contents, with a resultant increased positive intra-abdominal pressure. According to Broman, this increased pressure causes the soft and plastic liver to alter its form and to undergo pressure atrophy. In later stages there is a relative diminution in the size of the liver, it growing at a less rapid rate than the surrounding body tissues. Both processes, pressure atrophy and diminution in liver size, affect the two lobes of the liver equally in the beginning, but in later stages the left lobe of the liver becomes much smaller, thus establishing the marked asymmetry existent between the two lobes. The definitive asymmetry between the two lobes is attained in early childhood, for in the newborn the two lobes are in many instances nearly equal in size (Scammon).

Development of Liver Vessels. As shown by Mall (1906), the solid growing cords of liver cells (primitive hepatic trabeculae) in their ramifications soon come in contact with the two omphalomesenteric (vitelline) veins situated in the dorsal mesoduodenum at each side of the gut, as they proceed to the septum transversum, where they are returning blood from the yolk sac to the sinus venosus of the heart. During the fourth week the liver cords push into these veins and break them up into a network of numerous irregular channels known as the sinusoids of Minot (1900), the interiors of which are lined by reticuloendothelial (stellate Kupffer) cells derived from the local mesenchyme. Channels leading to the sinusoids become the venae advehentes; those leaving them are the venae revehentes. The caudal (distal) stubs of the omphalomesenteric veins will become the afferent vessel (portal vein); the cranial (proximal) stubs will give rise to the hepatic veins.

Very early (5 mm stage) several transverse anastomoses are established between the paired omphalomesenteric veins. These comprise (1) a caudal anastomosis ventral to the duodenum (preduodenal) immediately caudad to the hepatic diverticulum, (2) a retroduodenal, formed in the mesentery

caudad to the anlage of the dorsal pancreas, (3) a cranial, in the region of the porta hepatis (subhepatic), above the opening of the liver bile duct diverticulum, (4) a subdiaphragmatic anastomosis below the diaphragm and above the liver which connects the draining section (proximal stubs) of the two original omphalomesenteric veins.

The first three anastomoses are placed distally and enter into the formation of two rings disposed like a figure 8, one *ring being cranial, the other caudal.* Through these rings situated under the liver passes the duodenum. The fourth anastomosis is placed proximally, and after retrogression of the opening of the left omphalomesenteric vein receives the left venae advehentes as the left hepatic vein. Through retrogression of the left limb of the cranial ring and the right limb of the caudal ring and through the disappearance of the caudal (preduodenal) anastomosis of the original two omphalomesenteric veins, an asymmetric S-shaped vessel, the portal vein, is formed. Actually, then, the portal vein arises from the retroduodenal anastomosis between the omphalomesenteric *veins and a section of the right omphalo*mesenteric vein (right limb of the cranial ring). Whereas the right branch (ramus arcuatus) of the portal vein is directly continuous with the stem from the beginning, its left branch (ramus angularis) furnished by the subhepatic (cranial) transverse anastomosis becomes associated with the left umbilical vein and with the occlusion of the latter at birth joins the portal vein. The portal tributaries, viz., the superior mesenteric and the lienal veins, are independent formations. The superior mesenteric joins the portal below the pancreas via its dorsal connection with the retroduodenal (intermediate) anastomosis. It is not a continuation of the left omphalomesenteric *(vitelline) vein, but a* vessel which replaces the vitelline veins after these cease their function with the early retrogression of the yolk sac.

With the progressive lateral expansion of the growing liver mass, the liver cords likewise come in contact with the original paired umbilical veins (placental circulation) that proceed from the placenta through the umbilical cord and ascend on the lateral body wall to end in the sinus venosus, next to the omphalomesenteric veins. The tapped umbili*cal vein for a short period, routes the* umbilical blood through the sinusoids of the liver. Subsequently, the entire right umbilical vein and the proximal segment of the left umbilical vein undergo regression. The left umbilical veins then become attached to the left omphalomesenteric (or a branch of it) entering the left lobe of the liver. As a greatly enlarged vessel, it functions until birth, when it becomes occluded to form the round ligament (ligamentum teres).

Initially, the blood from the left umbilical vein, in its course through the liver, passes through the right omphalomesenteric (vitelline) vein, it being larger than the left, to reach the sinus *venosus. With the enlargement of the* right lobe of the liver, a more direct route of placental blood flow is established through the formation of the ductus venosus of Arantius. This diagonal channel formed in the lesser omentum (ventral mesogastrium) represents a longitudinal sinusoidal anastomosis between the subhepatic (cranial duodenal) and the subdiaphragmatic transverse anastomosis of the omphalomesenteric veins. It affords a means whereby the purer blood from the placental circulation does not have to pass through the sinusoidal portal circulation but reaches the inferior vena cava directly. After birth, with the cessation of the placental circulation, the ductus venosus becomes *occluded and forms a solid cord, the liga*

mentum venosum to which the gastrohepatic ligament is attached. The left umbilical vein becomes the round ligament (ligamentum teres) coursing from the umbilicus to the liver in the free margin of the falciform ligament.

With the cessation of the placental circulation and the subsequent occlusion of the umbilical veins and the ductus venosus, the portal vein becomes the afferent vessel of the liver (cor abdominale, vena arteriosa of the ancient writers) carrying blood from the intestinal capillary bed. A treelike pattern of the portal circulation is thereby established, the roots of the tree representing the capillaries of the intestine, the branches of the tree representing the sinusoidal capillaries in the liver. In addition, the sinusoids serve as a drainway of the oxygen-laden blood (25 per cent of the total blood going to the liver) carried by the hepatic artery. The hepatic veins (3 to 4) which join the vena cava inferior represent the efferent vessels and, as shown by Mall, come to the surface, whereas the portal vein never does. They are derived from the omphalomesenteric veins proximal (cranial) to the region where they become broken up by the growing liver tubules, the right omphalomesenteric vein persisting as the common hepatic vein. Tributaries to the hepatic veins are the sublobular veins, which in turn collect the blood from the central veins, these representing the common venous drainage of the glandular lobules.

As early as the fifth week a branch of the vena revehens dextra (communis) grows caudally into a fold of the dorsal mesentery. Soon liver tissue likewise grows into this fold, giving the vessel the appearance of a liver vessel. Actually it is part of the rudiment of the inferior vena cava, for the vessel descends caudally beyond the liver to establish connections with the caudal portion of the inferior cardinal veins. With the establishment of the inferior vena cava, the main stem of the vena revehens communis becomes resolved into the vena cava inferior and its main branches become the definitive hepatic veins.

Liver Anomalies

If in the development of the two vitelline rings about the duodenum the caudal ventral (preduodenal) anastomosis persists instead of the retroduodenal, then the portal vein will lie anterior to the pancreas and ascend in front of the duodenum instead of behind it. The right umbilical vein may persist instead of the left and join the portal vein and not its left branch. Bridges of hepatic tissue (pons hepatis) overlying the umbilical ligament in the left sagittal fossa and those overlying the inferior vena cava or the ductus venosus (Figs. 50, 51, 53, 58, 71, 83, 90) are to be interpreted on the following basis. At first these vessels, as well as the gallbladder, lie more or less completely surrounded by hepatic tissue. With the reduction in the size of the liver during development, these vessels come to the surface as free structures. If bridges are present, some of the original enveloping hepatic tissue remains. The bridges may be fibrous, in which case the interstitial tissue remained. Another striking proof of the actual reduction in the size of the liver is the formation of the appendix fibrosa, a fibrous appendage which is attached to the left lobe of the liver and which is united with the left triangular ligament, the two at times forming a phrenicohepatic recess (Fig. 61). The appendage is a remnant of the original interstitial tissue and occasionally has aberrant bile passageways in it which are in direct communication with the superior area duct of the lateral segmental duct, as shown by Healey and Schroy (1952) in corrosion casts.

Formation of the caudate lobe is dependent on the rotation of the stomach belonging to the right lobe when the stomach turns to the left and to the left lobe when it turns to the right for the peritoneal fold over the inferior vena cava cannot develop on the side toward which the stomach turns However formation of the quadrate lobe is dependent not on stomach rotation but on the position of the gallbladder and on the fact whether in fetal life a right or a left umbilical vein persisted Even with normal development of the liver the gallbladder may lie to the left of the quadrate lobe The ligamentum teres may lie to the right of it as was the case in one of the author s specimens (Fig 80) Judging by the position of the developing gallbladder in the ventral mesentery the quadrate lobe belongs to the left lobe and not to the right as commonly taught This fact is clearly demonstrable in 150 plastic corrosion casts of human livers made by Healey and Schroy of the Daniel Baugh Institute of Anatomy for in these (as described in Chapter 7) the quadrate lobe constitutes a part of the medial segment of the left lobe as far as its blood supply and its biliary drainage are concerned From this standpoint is explicable the fact that the quadrate lobe normally supplied by the middle hepatic may also receive branches from the left segmental branch of the left hepatic as frequently instanced in the author s illustrations (Figs 51, 55 66 97)

Since the liver is actively plastic its form is determined largely by the condition of the surrounding organs When these are altered as in partial or complete inversion the main lobes likewise become altered Essentially the size of the right or the left lobe depends on the way in which the stomach rotates Accessory livers i e detached pieces of hepatic tissue, occur rarely Frequent are long or short parietal grooves made by the overlying ribs (costal grooves) or by the wrinkles of the diaphragm (diaphragmatic grooves) Commonly present is a deep or a shallow fissure in the right lobe under the gallbladder made by a lateral extension of the porta hepatis on the visceral surface (Figs 57, 60 63 73 74 91) Cleft formation with pyramidal projections of hepatic tissue occurs on the left wall of the quadrate lobe (Figs 87 89) The tuber omentale on the left lobe may be excessively large (Figs 58 76 79) Long thin attenuated extensions of the left lobe with or without intermediate fibrous tissue may overlie the spleen (Figs 60 80) A bulge of the right lobe projecting below the right costal margin is known as the Riedel lobe, which sometimes reaches the right iliac fossa Congenital herniation of the liver through the diaphragm especially on the right side occurs frequently in infants the herniation preventing the normal development of the lung Herniation of hepatic tissue through the belly wall (evisceration) is less seldom In aged individuals the liver shrinks sometimes to less than half its normal size

An item not sufficiently stressed is the fact that the liver is attached not only to the diaphragm at the central tendon region (the bare area bounded by the coronary ligament) but also to the dorsal body wall in the region where the dorsal surface of the right lobe is firmly attached to it In this region the dorsal lamella of the right triangular ligament becomes continuous to the right with the parietal peritoneal overlying the kidney and the fold of the inferior vena cava In doing so it forms the hepatorenal (hepatocavoduodenal) ligament which forms part of the floor of the pouch of Morrison (space between liver colon duodenum and kidney)

Gallbladder, Biliary Ducts Pancreatic Ducts Duodenal Papilla Ampulla of Vater, Gallstones Sphincter of Oddi Sphincter of Lütkens Musculature of the Gallbladder, Comparative Anatomy of the Biliary Apparatus Developmental Anomalies and Atretic Conditions

Embryology As previously stated the liver diverticulum arises at a very early stage (1 3 mm) as an entodermal epithelial outgrowth from the ventral wall of the duodenum A round caudal expansion of this outgrowth gives rise to the ventral pancreas while the dorsal pancreas grows out as a separate diverticulum from the dorsal duodenal wall The hepatic diverticulum is at first a hollow cul de sac like protrusion which through a longitudinal furrow becomes divided into a cranial (hepatic) and a caudal (cystic) portion The cranial portion (pars hepatica) becomes the anlage of the epithelial hepatic trabeculae and of the epithelial lining of the hepatic duct and that of the main intrahepatic ducts Initially the pars hepatica is compact but it becomes broken up into a network of liver cords by invading mesenchyme containing branches of both omphalomesenteric veins The caudal portion (pars cystica) gives rise to the epithelial lining of the gallbladder the common bile duct and the cystic duct The latter three structures become solid epithelial cords by migration of parietal cells into the original lumen (Boyden 1926)

The solid stage of the gallbladder and the common bile duct occurs regularly even after the establishment of a lumen in the common bile duct (7 5 mm) and the cystic duct (16 mm) the distal end of the gallbladder is still impervious A clear cut lumen appears at the 18 mm stage the mucosa the muscularis and the serosa come in at the 29 mm stage (Lewis 1912) According to Broman (1927) the compact stage of the gall bladder and the biliary passageways lasts until the second or the third month when they become definitely hollow Reestablishment of a lumen in the biliary passageways is effected by a process of vacuolization of the solid core (Boyden) In the event this vacuolization is double a septate ductus choledochus (i e a common bile duct that is double in parts of its course) is formed

According to Lewis (1912) the hepatic duct in its earliest stage (9 4 mm) is a short stem connecting the main mass of the hepatic trabeculae with the common bile duct Initially it too is solid but at the 10 mm stage it develops a lumen Rudimentary additional ducts are common they may join the hepatic or the common bile duct but according to Bremer (1923) they never arise from the caudal portion of the hepatic diverticulum this being the anlage for the ventral pancreas Further data on the development of the bile ducts are to be found in the work of Keibel and Mall (1914) and in the article by Hammer (1926)

The origin of the spiral valve of Heister in the cystic duct is due to the fact that the mesodermal anlage of the cystic duct is fixed firmly and remains relatively short whereas the entodermal

[6] Sir Arthur Keith described the embryology of the gallbladder and the bile ducts as follows The hepatic diverticulum from which the liver buds arise may be regarded as a direct extension of the wall of the foregut From its hinder part are developed the common bile duct the gall bladder and the cystic duct formed at the junction of the gall bladder and common bile duct The hepatic ducts arise within the stalks of the solid hepatic buds At first the gall bladder lies in the ventral mesentery (gastrohepatic omentum) a position which is permanent in some vertebrates and may occur as a rare anomaly in man In the second month it becomes included and buried in the hepatic tissue at a late date it assumes its superficial position The lumen of the ducts is occluded by an epithelial proliferation until the third month Occasionally the bud for the gall bladder divides *giving rise to* a bifid double gall bladder (*Human Embryology and Morphology* ed 3 p 2[illegible]1 London Arnold 1913)

part of the duct grows extensively in length during the third month, so much so as to force it into spiral form (Rietz 1917)

The mesenchymatous network of the liver anlage is derived from several sources coming mainly from the regional supporting tissue of the liver in part from the blood stem cells and the blood vessels (Mollier 1909) Mollier has shown that from its earliest appearance the liver is an important blood forming organ being mainly erythropoietic This function does not cease until several weeks after birth The exact origin of the liver blood stem cells is still largely unsolved Mollier of Munich University (1909) deriving them from the reticulum Aron (1921) from the liver cells themselves as shown to the author by Aron and Bouin at Strassburg University The problem of erythropoiesis in the embryonic liver is discussed fully according to the pertinent literature in the author's review of the subject published in the *Folia Haematologica* in 1931 (vol 45 pp 75–128) This extensive review on erythropoiesis was written after the author had been instructed by Downey of the University of Minnesota (a pupil of Weidenreich with whom the author discussed the problem 1922) by Ferrata of Siena University Italy and by Maximow of Russia later of Chicago University in extensive studies in their laboratories regarding morphology and derivation of blood stem cells

Duodenal Papillae and Their Associated Ducts

The main pancreatic duct was discovered in the rooster by Moritz Hoffmann in 1641 and was first dissected in man in 1642 by the German anatomist Wirsung after Hoffmann had shown him his curious finding which at first thought was deemed to be a lymph vessel The major duodenal papilla common to the bile duct and the pancreatic duct was noted first by Bidloo in 1685 The anatomy of the accessory pancreatic duct and of the minor papilla was described first by the Italian anatomist Santorini (1775) He gave the first accurate concept of the relations of the bile and the two pancreatic ducts to each other and to the two papillae through which they discharge their contents into the duodenum although Vesalius in his *Fabrica* (1543), on the basis of his own dissections long previously had established the fact that not the smallest part of the bile vesicle was extended into the stomach as generally was believed before his time, because of Galenistic teaching

Santorini's work forgotten for nearly a century was resuscitated by Claude Bernard (1856) through his investigations on the physiology of the pancreas By injections of metallic mercury into the bile and pancreatic ducts he determined their mode of termination and function In 1898 Charpy gave a description of the variations and the anomalies of the pancreatic ducts Langerhans (1869) in his dissertation gave the first detailed microscopic anatomy of the pancreas and with it began the modern physiologic interpretation of the gland Initial descriptions of the four major types of junction of the pancreatic duct with the common bile duct were made by Letulle and Nattan Larrier (1898) Mayo Robson (1900, 1904) and Ruge (1908)

Opie (1903) one of America's greatest pathologists was among the first to state that in 10 per cent of 100 cases the duct of Santorini was functionally as well as structurally the chief outlet of the external pancreatic secretion This same percentage was obtained by Simkins (1931) in 25 specimens and by Millbourn (1950) in 200 specimens The percentage was reduced to 2 per cent by Rienhoff and Pickrell (1945) for they observed only 4 cases in 100 specimens

in which the accessory pancreatic duct carried the major secretion

Baldwin of the University of Cornell (1911) presented a major pioneer investigative work on the pancreatic ducts In a study of 100 specimens he showed that (1) the major and the minor duodenal papillae are present in all cases (2) in 82 per cent the accessory pancreatic duct is patent and in 10 per cent it ends blindly (3) the accessory duct courses in a plane ventral to that of the main pancreatic duct and is restricted to the cephalic and the ventral segments of the head its orifice (minor papilla) being situated cephaloventrad to that of the major papilla on a prominent transverse mucous membrane fold (4) the lumen of the bile duct undergoes a marked constriction at the duodenal wall before its junction with the pancreatic duct (5) in 80 per cent pancreatic tissue surrounds the bile duct for a distance varying from 0 5 to 5 cm while in 15 per cent the duct grooves the tissue of the head of the pancreas (6) the mode of union of the bile and pancreatic ducts comprises two types In one type the two ducts fused at the level of the duodenal wall but the lumina did not fuse until the papilla had been entered A thin mucous membrane separated the two ducts for at least one half of the papilla where the true ampulla began In the other type there was a complete isolation of the two ducts Each duct opened side by side in the duodenum through the major papilla no true ampulla being formed in these cases

Anatomic texts vary considerably as to the description and the illustration of the accessory pancreatic duct Some texts depict Santorini s duct as draining the cephalic others as draining the caudal part of the head of the pancreas In an investigation of 25 specimens Simkins of the Philadelphia General Hospital (1931) found 3 groups (1) Santorini s duct was found present only in the cephalic part of the head of the pancreas (2) it was present only in the caudal part of the head (3) it was present in both the caudal and the cephalic parts of the head According to Rienhoff and Pickrell Santorini s duct invariably lies on a plane ventral to that of the main duct and communicates with it in the head of the pancreas near the neck region

Erik Millbourn of the University of Lund Sweden (1950) has presented the most recent extensive investigation on the anatomy of the excretory ducts of the pancreas and their relation to each other to the bile duct and to the duodenum To ascertain full display of the pancreatic ducts in 200 specimens he made a closure of the papillary orifice in the duodenum by sewing it up Thereupon he injected a 20 per cent barium sulfate solution into the bile duct and when necessary made supplementary injections into the pancreatic duct from the tail of the pancreas The contrast injected specimens were then studied in x ray films and in gross dissection

Millbourn found that the bile duct and the duct of Wirsung always terminated at the greater papilla and the duct of Santorini at the lesser papilla irrespective of whether the latter duct functioned as an accessory channel or as the sole or the main excretory duct Patterns of the excretory pancreatic ducts in 200 specimens comprised the following types

I The pancreatic duct (of Wirsung) terminated in the bile duct in 171 cases (85 5 per cent) The duct of Santorini was demonstrable in 88 of the cases

II The bile duct and the pancreatic duct (of Wirsung) terminated on a common papilla in 11 cases (5 5 per cent) The duct of Santorini was found in 5 cases

III The bile duct and the pancreatic duct (the latter here being the duct of Santorini functioning as the main or the sole excretory duct) terminated at sepa

rate points in the duodenum in 18 cases (90 per cent) A small duct of Wirsung was observed in 13 of the cases with an anastomosis between the duct system of Santorini and Wirsung in 2 of these cases

From his studies Millbourn concluded that the sole or the main excretory channel of the pancreatic parenchyma is the duct of Wirsung in about 90 per cent of the cases and the duct of Santorini in about 10 per cent As a rule the duct of Wirsung enters the bile duct *at the latter s distal end before its* termination on the greater papilla of Vater Exceptionally (1 in 20) it enters together with the common bile duct at a common *papilla In cases* where the duct of Wirsung was the main duct the duct of Santorini was demonstrable in about 50 per cent having patent communication with the duodenum in 40 per cent and ending blindly in the lesser papilla in 10 per cent In about every other case with open communication the duct of Santorini was sufficiently large to function as a substitute for the duct of Wirsung Santorini s duct functioned as the main or the sole excretory duct in 10 per cent of cases It invariably coursed ventrally to the duct of Wirsung and terminated at the lesser papilla situated cranioventrally to the greater papilla

Exact location of the minor duodenal papilla according to Millbourn should be borne in mind in performing gastric resections At the operative loosening of the cranial part of the duodenum from the pancreas the duct of Santorini may be divided or injured *Ordinarily, this would not be a serious injury but, in those cases where the duct of Santorini is the main or sole excretory duct (10 per cent Millbourn 1950) without anastomosis to the duct of Wirsung or in cases where the duct of Santorini drains a large portion of the pancreas injury of it may result in postoperative acute pancreatitis*

After considering the embryology of the pancreas Millbourn maintained that from a developmental standpoint only the 6 pancreatic duct variants which he depicted are possible and that the reports in the literature to the contrary probably are due to faulty observation Millbourn found no sex differences of duct types as claimed by Hjorth (1947) Finding an open communication of Santorini s duct with the duodenum in 44 per cent in men and in only 14 per cent in women Hjorth thought that this anatomic difference might explain the predominance of biliary diseases in women for a Santorini duct in open communication with the duodenum would act as a *safety valve for the increased pressure in* the pancreatic duct and thus reduce the possibility of reflux of pancreatic juice to the common bile duct

To review the older literature on variants of the pancreatic ducts especially as regards the duct of Santorini would entail a description of so many concepts as to confuse the issue The following two outstanding investigations on the duct of Santorini however should be recalled

Schwartz of the University of Heidelberg (1926) after an examination of 64 specimens reported that the Santorini system was missing in 25 cases was rudimentary in 3 cases communicated with Wirsung s duct in 23 cases was independent in 8 cases and was the sole outlet in 3 cases In all instances the duct of Santorini lay in the head of the pancreas *ventral to the duct of Wirsung*

Naatanen of the University of Helsinki (1941) investigated 100 pancreases in which the duct system had been injected with a colored fluid In 39 cases the duct of Santorini was only a branch of the duct of Wirsung and was not connected with the duodenum Santorini s duct was patent in 18 per cent Hence approximately *only in* every fifth case

could pancreatic secretion enter the duodenum when the duct of Wirsung became occluded from a stone or a tumor formation The following types of Santorini ducts were encountered (1) cranial duct the main one but not connected with the caudal (1 per cent) (2) cranial duct the main one but connected with the caudal (3 per cent) (3) Wirsung s duct the only one Santorini s duct connected with the duodenum (26 cases) (4) Santorini s duct had lost a connection with the duodenum (39 cases) (5) Santorini s duct the only one present (25 cases) Three of these types according to Millbourn are identical with those he encountered in his x ray studies of 200 specimens injected with contrast medium to wit with the types he depicted as W1 S1 and S2

Sites of the Duodenal Papillae Reports in the literature on the distance of the major duodenal papilla of Vater from the pylorus in the adult vary considerably this being due to differences in constitution age and mode of measurement According to Maeda (1924) a pupil of Adachi at the University of Kyoto the major papilla lies about in the middle of the duodenum if the distance is measured from the pylorus to the opening along the concave side of the duodenum In 62 preparations of the entire duodenum which he illustrates he found the distance to vary as a rule from 70 to 79 mm with extremes from 40 to 159 mm Letulle and Nattan Larrier (1898) found extremes of 52 to 98 mm the average being 7 to 8 cm Stracker (1909) reported the distance to vary from 55 to 142 mm it most commonly being between 80 to 95 mm Sterling (1950) found the distance to vary in most instances from 80 to 120 mm The distance between the pylorus and the lesser papilla varies from 3 5 to 12 cm the average being 7 cm (Keyl 1926) Millbourn (1950) found the distance to vary from 5 5 to 9 cm the average being 8 cm [6]

The distance from the lesser to the greater papilla varies from 0 9 to 3 5 cm the average being 2 cm (Baldwin 1911) Letulle and Nattan Larrier (1898) found variations from 10 to 35 mm the average being 18 mm Maeda (1924) found the distance to vary most frequently from 20 to 29 mm with extremes from 10 to 59 mm Sice of France (1911) reported a distance of 29 mm while Clairmont of Switzerland (1923) reported one of 3 mm Recently Hughes and Kernutt of Australia (1954) found the distance to average 21 mm The distance from the mouth of the major papilla to the point of junction of the two ducts in the ampulla averages 4 8 cm (Baldwin) Most commonly the papilla minor is calculated as being situated about 7 cm below the pylorus and 2 cm above the papilla major In each of his 200 specimens Millbourn (1950) found the lesser papilla to lie oroventrally to the greater papilla in 8 per cent of 182 cases the duct of Santorini had a blind termination in the lesser papilla In his specimens the duct of Wirsung generally entered the common bile duct at the latter s distal end before its termination on the greater papilla and only exceptionally (about 1 in 20) did it enter together with the bile duct at the common papilla of Vater

Constitutional Variants The duct of Santorini and the duct of Wirsung may have a common orifice on the major

[6] In mammals according to Mann Brimhall and Foster of the Mayo Clinic Minnesota (1920) the distance between the pylorus and the point of entry of the bile duct in the duodenum is decidedly more varied than in man it being short in some animals (horse 10 to 20 cm) and very long in others (ox 50 to 70 cm) In small animals the distance varies from 0 5 to 1 5 cm from the pylorus in the rabbit and from 0 4 to 0 8 cm in the guinea pig from 1 5 to 2 5 cm in the rat and from 4 to 5 cm in the pocket gopher These measurements show that the entry of the bile duct into the duodenum is relatively closer to the pylorus in species without a gallbladder than in those possessing one

papilla (Strauss, 1923). The common bile duct and the *pancreatic duct* may anomalously open into the papilla minor (Clairmont, 1923). The major or the minor papilla may be double (Holzapfel, 1930; Patzelt, 1936) and even triple (Schirmer, 1893; Baldwin, 1911). Pancreatic tissue *may be found in the* papilla major or minor and in the plica longitudinalis (Patzelt, 1936). The *minor papilla may be absent* (4 per cent), impervious or markedly regressed (Keyl, 1926). Clairmont of the University of Zurich (1923), *in his report on* 100 duodenal resections for carcinoma, discussed 10 variants of openings of the *main and the accessory pancreatic ducts*, 6 of which he encountered in his own material of 50 cases. In 17 cases the outlet of the pancreatic ducts lay in the direct path of his proposed sectioning. In 7 deaths after duodenal resections, 5 showed surgical implications of the pancreatic duct. Clairmont stated that the duct of Santorini *always comes to view from below and behind*, that it may be confused with a blood vessel and that in *8 per cent it constitutes the main pancreatic duct*.

Cestari and Fantini of the University of Padua (1933) showed that the major papilla along with the intraparietal portion of the *common bile duct* has an autonomic nerve supply comparable with that of the intestine, being composed of a deep plexus situated between the two muscle layers and a superficial plexus located *in the submucosa*. But Kiewicz of Warsaw, Poland (1936), in a very *comprehensive anatomicophysiologic* study of 125 cases of bile peritonitis without perforation of the biliary passageways, asks the question why, in most cases of this *condition*, the papilla major is impervious and then proceeds to explain it on the basis of Westphal's (1923) concept of the mode of contraction of the sphincter of Oddi. Sandblom of Orebro Lanslasarett (1933) places emphasis on the fact that a gallbladder *completely cut off from its nerve supply* continues to function and, in view of this, he claims that evacuation of the *organ may be due to a hormonal influence*. For an accurate and comprehensive evaluation of the problem of emptying *of the gallbladder in the child, in old* age, in pregnancy and under various other conditions the reader is referred *to the pioneer investigative contributions* of Boyden listed in volume 118 of the *Anatomical Record* (January, 1954).

New Anatomy of the Pancreatic Part of the Common Bile Duct

This topic is of primary interest to every biliary surgeon, *for*, as stated by the late Lahey of *Boston*, we urgently need more investigation on the retropancreatic part of the common duct, it being so *often subject to operative exploration*. Up until about 1945, it was believed generally that, as the common bile duct approached the second part of *the duodenum in an oblique direction* in most individuals it passed through the head of the pancreas in a complete or *incomplete tunnel* and thereby became an *intraglandular structure not readily* accessible and *explorable without cutting* of pancreatic tissue. Today, as shown by a group of South American anatomists and surgeons (in nearly 1,000 dissections)—*in particular by* Smanio of the Department of Anatomy of the School of Medicine of the University of São Paulo, Brazil (1954)—we know that *in 60 per cent of cases (200 bodies his sample) the choledochus in its* retropancreatic portion is easily accessible. Either it is *not covered by pancreatic* tissue at all, being covered merely by a sheath of connective tissue (*Treitz's fascia, 15.5 per cent*), *or it is only apparently* intrapancreatic, being covered to a small extent by a lingula *of pancreatic* tissue or by two lingulae, the lips of which are juxtaposed at the level of the

posterior surface of the choledochus. In all instances where the lingula (laminar extension of the pancreatic head) exists there are definite connective tissue cleavage planes predominantly through which an easy access can be made to the choledochus without removing it from its bed. In 10 per cent of cases (200), however, the lingula is thick, covering the choledochus completely (30 per cent) in its proximal two thirds or its proximal half, thus rendering isolation and visualization of the choledochus very difficult, for the free border of the lingula can be confused readily with the upper border of the pancreatic head.

With arduous, highly technical manipulation regarding the detection of existent connective-cleavage planes and spaces about the lingula of pancreatic tissue over the choledochus, Smanio was able to free the common bile duct in all but 3 cases without sectioning of the pancreas, whereas Finochietto (1912) had to section pancreatic tissue to free the choledochus in only 5 of 100 cases. It was primarily Degli (1945) who (in a thesis presented to the São Paulo University of Brazil) devised the simple technic of divulsion of the common duct, having shown that a pancreatic lingula may be double, one caudal, the other cranial, one large or small, as the case might be.

Smanio's extensive account of his observations in 200 bodies on the anatomic relations of the pancreatic part of the choledochus and method of exposing it freely was published in the *Journal of the International College of Surgeons* (August 1954). In his review of the literature on the retropancreatic portion of the common duct he cited the findings and the opinions of 24 investigators. Beginning with Letulle and Nattan Larrier of France (1898), who were among the first to speak of a "languette" as being present between the duodenum and the common duct, Smanio listed and evaluated the contributions made by the South American group of investigators, to wit, those of Belou (1915), 100 bodies; Finochietto (1912), 100; Leiva (1943), 100; Nogueira (1944), 31; Degni (1945), 75; Freitas (1948), 110; and Bustos (1951), 54. To these are added the observations made by Ruge (1908), 13 bodies; Baldwin (1911), 100; Maeda (1924), 60; Cameron of Australia (1924), 100; Fuchs (1926), 50; Yamaguchi of Japan (1930), 110; Nuboer (1931), 75; Chlyvitch and Kozintsev (1937), 100; Niitinen (1944), 100; Sterling (1949), 80; and several other authors.

Smanio's investigations were made on 200 autopsy specimens (100 white, 100 Negro) that were obtained from the Department of Pathologic Anatomy of the Medical School of the University of São Paulo, Brazil. After the specimen had previously been fixed in a 10 per cent solution of formaldehyde, dissection was begun on the posterior surface of the head of the pancreas in order to identify the pancreatic lingulae in relation to the pancreatic segment of the choledochus. In every instance the lingula was carefully dissected with fine scissors, care being taken not to withdraw the choledochus from its bed. After a statistical analysis of his observations Smanio classified the specimens into the following 5 groups:

(1) A pancreatic lingula of caudal base and of variable extent partially covered the choledochus (42.5 per cent). (2) A lingula of caudal base covered the entire pancreatic part of the choledochus (30 per cent). (3) No pancreatic lingula was present, the duct being juxtaposed to the posterior surface of the head of the pancreas or placed in a more or less deep furrow covered by a membrane (fascia of Treitz, remnant of the primitive mesoduodenum) containing lymphatics, arteries and veins (16.5 per cent). (4) The lingula was double, an upper one at the cranial base and a lower one at the caudal base, always juxta-

posed to the free border (9 per cent) (5) Cases presenting less frequent morphologic variations (2 per cent)

Among group 5 Smanio included one case of a prepancreatic choledochus and 3 cases in which besides the dissectable pancreatic lingula there was a slender bridge of pancreatic tissue over the choledochus that had to be resected in order to free and expose the common duct completely

The occurrence of a prepancreatic choledochus is very rare Nuboer (1931) 2 cases in 75 bodies Chlyvitch and Kozintsev (1937) 1 in 100 Naatanen (1941) 1 in 100 Degni (1945) 2 in 75 and Smanio (1954) 1 in 200

In his summary Smanio stated

> In virtually 60 per cent of the cases the choledochus in its retropancreatic portion is easily accessible either because it is not covered by pancreatic tissue or is so covered only in a small portion of its length or because it is covered by two lingulae the *lips of which are juxtaposed to the level* of the posterior face of the duct In 40 per cent of the cases the lingula is thick it covers the duct entirely (30 per cent) in its proximal two-thirds or its proximal half Under these conditions the isolation of the *choledochus* is made *very difficult* The variations observed with reference to the two ethnic groups and the two sexes provided no significant statistical variations

Thus in the opinion of the present writer pancreatic tissue resembles thymic tissue in structural disposition for here likewise by careful dissection of connective tissue planes the original embryologic right and left lobes of the gland no matter how differently disposed in the adult may clearly be isolated and analyzed into their constituent lobules (20 or more) a task every freshman student in anatomy can assay with interest and instruction A comparable anatomic situation exists as regards the position and the course of the facial nerve in the parotid gland As shown by the British surgeon Bailey (1948) the facial nerve is sandwiched in the parotid gland and with dexterous surgical manipulation readily can be exposed without undue sectioning of the parotid tissue

Proceeding to other reports on the relations of the common duct in the pancreas the following observations are of interest and importance

In an examination of 100 specimens Naatanen of the University of Helsinki (1944) found the following relations of the common duct (1) it coursed in a furrow on the dorsal surface of the pancreas covered by connective tissue (53 per cent) or by a thin sheath of pancreatic tissue 2 to 5 mm thick (34 per cent) (2) it coursed through a tunnel 30 to 60 mm long which was always closer to the dorsal surface of the pancreas being 4 to 15 mm from it (12 per cent) In direction the course of the common duct varied being straight curved and in some instances angular (14 per cent) About 20 mm from the opening it commonly made a bend in a caudal direction and ultimately became smaller widening at the ampulla When the cystic duct joined the hepatic duct *in the region of the pancreas (45 cases)* the choledochus had a length of 60 mm and in 1 case was but 30 mm long In the flattened condition the average width of the duct was 8 mm Only one *instance was observed* in which the common duct ran on the ventral surface of the pancreas

Nuboer of the University of Utrecht (1931) reported that in 50 of 75 cases (67 per cent) the common bile duct passed through a tunnel of pancreatic tissue and that in 20 cases it ran in a gutter on the back side of the pancreas The length of the ductus hepatocholedochus varied from 7 5 to 15 cm (average *9 8 cm) that of the common* bile duct varied from 3 to 9 5 cm (average 6 3 cm) The length of the pars duode

nals of the common duct varied from 0.7 to 2 cm (average 1.1 cm.)

According to Hughes and Kernutt of Australia (1954) the common duct comes into intimate relation with the wall of the duodenum in the last 10 to 15 mm of its course In the 30 formalin hardened specimens investigated the pancreatic and common bile ducts joined 2 to 10 mm outside of the duodenal wall and were bound together—i e enveloped in a common adventitial sheath—the entire mass forming a smooth elevation that projected on the external surface of the duodenal wall At the junction of the pancreatic and common bile ducts the diameter of the common duct just above this transition varied from 1 to 14 mm (average 8.5 mm.) and the diameter of the pancreatic duct varied from 2 to 7 mm (average 3.8 mm.) When the pancreatic duct was opened the same sudden narrowing was apparent in its lumen as was observed in the common bile duct The length of the intramural portion of the combined ducts varied from 5 to 25 mm with an average length of 15 mm (idem Poirier and Charpy 1912) In respect to the sudden narrowing of the common duct Hughes and Kernutt stated that the orifice *leading into the intramural portion* may be eccentrically situated with the formation of a shallow pouch which may be on the duodenal side or on the pancreatic side In 12 cases no pouch existed for the orifice was located centrally In 11 of their specimens a thin septum completely separated the two ducts so that no ampulla was present

Mode of Duct Union and of Their Orifices into the Duodenum

Letulle and Nattan Larrier of Paris (1898) were among the first to classify and illustrate the various types of openings of the common bile duct and the pancreatic duct into the duodenum via the ampulla of Vater or otherwise As stated in their article published in the *Bulletin of the Anatomical Society of Paris* (5 S vol xii) they investigated 21 specimens previously treated for 24 hours with Muller's fluid The distance of the ampulla from the pylorus showed extremes of 52 to 98 mm the average being 7 to 8 cm The distance between the ampulla and the minor papilla varied from 10 to 35 mm the average being 18 mm The common bile duct coursed obliquely through the intestinal tunics The pancreatic duct at 5 cm from its termination had a circumference of 6 to 7 mm but many showed a dimension of 10 12 13 or 17 mm

The duct openings into the duodenum comprised the following types (1) the ampulla was absent The choledochus had the only opening into the duodenum as the duct of Wirsung opened laterally into the choledochus (3 cases) (2) the two ducts emptied in a true ampulla the two ducts having previously united at an angle and being separated by a membrane (6 cases) (3) the two ducts previously united at an acute angle opened in the same plane above a cupula form depression no ampulla being present (8 cases) (4) the two ducts opened simultaneously on the same plane *having united long before opening* into the duodenum (5) no ampulla was present (4 cases)

Letulle and Nattan Larrier found nerve cells to be very numerous in the region of the ampulla They maintained that the histologic details may explain the different spasmodic contractions of one or the other channel and in this regard may account for the different varieties of cancer occurring in the vaterian region

Pedro Belou Professor of Anatomy at the University of Buenos Aires Argentina in his classical monograph published in 1915 classified the terminal endings of the bile and the pancreatic ducts (as observed in 50 specimens) into

two groups (1) cases in which the tubercle of Vater was present (62 per cent) and (2) cases in which the tubercle was absent (38 per cent) When the tubercle of Vater was hollow (26 per cent), it had an ampulla with one or two orifices at its bottom for the ducts When the tubercle was solid (36 per cent) its vertex contained one or two orifices for the ducts In the second group (i e when the tubercle of Vater was absent) it was replaced by a single orifice for both ducts or by two orifices corresponding to the terminal part of the choledochus and the pancreatic ducts or by a bulbar depression having two separate orifices for the ducts The distance of the tubercle from the pylorus varied from 8 to 15 cm the average being 11 cm The ampulla varied from 4 to 9 mm in width and from 3 to 7 mm in length The superficial surface of the tubercle was not smooth for in 60 per cent it contained crescentic folds of mucous membrane

Ernest Ruge of the Berlin City Hospital Germany (1908) likewise was among the first to classify and illustrate the mode of orifices of the pancreatic and bile ducts into the duodenum In a study of 43 specimens he found the following types (1) duodenal diverticulum with a break in the mucosa between the two ducts (2) septal wall between the ducts just before their ending in the diverticulum (3) common opening into the duodenum but without a common diverticulum and (4) separate openings into the duodenum with a diverticulum only on the choledochus

Mann and Giordano of the Mayo Clinic (1923) classified the types of orifices of the pancreatic and bile ducts encountered in 200 necropsies as follows (1) bile and pancreatic ducts open separately contiguous to each other or at separate points (31 per cent) (2) both ducts open into a shallow ampulla 2 mm from the apex (45 per cent) (3) both ducts open into an ampulla 2 to 10 mm from the apex (20 per cent) (4) Wirsung s duct absent or reduced to a fibrous cord (4 per cent)

Mehnen, a German navy officer (1938) after an examination of 449 autopsy specimens, classified the types of duct openings as follows (1) separate opening of the choledochus and the duct of Wirsung in two papilla (19 cases 4 per cent) pancreatic duct enters caudally usually 3 to 4 mm from the papilla of Vater (2) separate openings of both ducts in one papilla (151 cases 34 per cent) (3) common opening of the ductus choledochus and the duct of Wirsung whereby both ducts form a common compartment i e the diverticulum of Vater that may attain a length of 8 mm (248 cases 55 per cent) (4) opening of the pancreatic duct into the ductus choledochus over 8 mm removed from the papilla of Vater without a diverticulum (27 cases 6 per cent)

After a study on pancreatitis based on dissections of 250 autopsy specimens Rienhoff and Pickrell of Johns Hopkins University (1945) noted the following duct systems (1) no junction of the pancreatic and bile ducts each entering into the duodenum by a separate orifice (29 per cent) (2) the ducts were contiguous the dividing septum terminating 1 to 2 mm from the apex of a common orifice (37 per cent) (3) a true ampulla varying from 3 to 14 mm from the apex of the orifice and having an average diameter of 3 mm (32 per cent) (4) the main pancreatic duct was reduced to fibrous cord the accessory pancreatic duct carrying the major secretion (2 per cent)

Rienhoff and Pickrell found an accessory pancreatic duct in each of the 100 specimens dissected for that purpose In the majority of cases (67 per cent) it was restricted to the ventral and the cephalic parts of the head After injection of air of dyes or of both an intraglandular communication between the

two ducts could be established in only 89 instances In 27 per cent the accessory pancreatic duct did not communicate with the duodenum Among anomalies noted were a looping of the main pancreatic duct and a specimen with three papillae In this connection it may be noted that Howard and Jones (1947) in their experimental studies of impacting the ampulla with stones were able to show that the duct of Santorini was patent from the duct of Wirsung to the duodenum in 54 (36 per cent) of their 150 specimens

After a study of 50 bodies Holzapfel of Dortmund Germany (1930) reported the following types of duct orifices (1) separate openings of the two ducts in one papilla (30 cases) (2) separate openings of the ducts in two papillae (9 cases) (3) common opening in one papilla (10 cases) In one case the two ducts united in the papilla In the newborn two papillae were often encountered

Cholangiographic Method of Visualization Realizing the technical shortcomings in the preparation of the ductal system Hjorth of the Carolina Institute (1947) and Millbourn of the University of Lund Sweden (1950) examined the types of openings of the pancreatic and bile ducts as revealed by the use of cholangiography first introduced by Mirizzi (1932) By injecting contrast medium under low pressure into the bile duct (Millbourn) or the pancreatic duct (Hjorth) of autopsy specimens and noting its reflux the course and the relations of the pancreatic duct could be visualized in the excised specimens of which Hjorth examined 100 and Millbourn 200 Three types of openings were recognized and were found to occur in about the same percentage by both authors As reported by Millbourn (1942) the types comprise (1) pancreatic duct opens into the bile duct at a variable distance from the opening on the greater papilla of Vater in the duodenum (171 cases 85 per cent) (2) pancreatic and bile ducts open close by each other in the duodenum *on* the common major papilla (11 cases 5 per cent) (3) pancreatic and bile ducts open into the duodenum at separate points (18 cases 9 per cent)

It is important to note that both Hjorth and Millbourn expressed doubt as to the reliability of the cholangiographic method to obtain exact visualization of the bile and pancreatic ducts in the living (*in vivo*) as was possible in their contrast injected excised specimens Hjorth refers to the works of Liedberg (1940) and Schuberth (1940) who claimed that ***instrumental exploration of the common duct may obstruct the passage of contrast medium*** to the duodenum Furthermore the statistics on the frequency of reflux of contrast

TABLE 1 REFLUX OF CONTRAST MEDIUM INTO PANCREATIC DUCT FOLLOWING OPERATIVE AND POSTOPERATIVE CHOLANGIOGRAPHY *

	No OF CHOLANGIOGRAPHICALLY STUDIED CASES	REFLUX OF CONTRAST MEDIUM INTO PANCREATIC DUCT (*per cent*)
Hjorth (1947)	130	17
Liedberg (1941)	53	11
Millbourn (1943)	181	10
Rudstrom (1941)	329	33
Hulten (1939)	110	21
Leven N L (1938)	91	23
Colp and Doubilet (1938)	35	20
Schuberth and Sjogren (1941)	—	17
Robins and Hermansson (1936)	25	16
Bernhard (1937)	—	10
Hunt Hicken and Best (1937)	56	9
Stenstrom (1940)	57	7

*From Millbourn *Acta Anat* 9 5 1950

medium established by means of cholangiograms are highly inconsistent and in his opinion fail to give an anatomico physiologic or pathologic possibility of communication between the common bile duct and the pancreatic duct or vice versa Millbourn came to the same conclusion for in the table on page 67 taken from his work (1950), reports on the frequency of reflux varied from 7 to 47 per cent A comparable table of reflux variants was made by Sterling of the University of Pennsylvania (1949) who in his own 50 cases observed a reflux into the pancreatic duct on only 4 occasions

Ampulla of Vater

Opinions are strikingly at variance as to what constitutes an ampula of Vater (1720) Is it the same as the duodenal diverticulum or the diverticulum papillae of Vater? Is it always present in the adult or is it merely an embryonic structure? Is it a mass or a space? Does the ampulla belong to the pancreatic duct or to the bile duct? Does the pancreatic duct open into the bile duct or is the situation the reverse? What role does the ampulla and its circular musculature play when it becomes impacted by a biliary calculus allowing a reflux of bile into the pancreatic duct? Could a reflux of pancreatic juice into the bile duct via a common ampulla be the cause of chronic diseases of the gallbladder as claimed by Hjorth (1947) or of stone formation as claimed by Mehnen (1938) who found the anatomic possibility of reflux to be 61 25 per cent in 449 cases? What constitutes a perivaterian diverticulum and how is it related to the major duodenal papilla?

First and foremost it is a well established fact that the anatomic arrangement whereby the bile and pancreatic ducts become converted into a communicating system via a diverticulum or an ampulla is by no means the usual anatomy for a distinctly measurable ampulla according to Rienhoff and Pickrell (1945) is present in less than one third of the population In the remaining population the pancreatic and bile ducts open separately (29 per cent) or contiguously with a septum between them (37 per cent) On an embryologic basis Boyden (1937) maintains that in most adults the ampulla is a vestigial structure for a comparative embryologic study of the ampulla in opossum guinea pig dog and man gave evidence of a progressive *involution of the ampulla* in the sense that in man the confluence of the bile and pancreatic ducts starts outside of the intestine but in the course of development the zone of junction becomes drawn into the duodenal wall (Schwegler and Boyden 1936) Sterling s (1952) startling contention that in the adult the ampulla does not exist at all will be discussed later

When present the ampulla supposedly is formed in the following manner As the bile duct passes obliquely through the longitudinal and circular muscles of the duodenal wall (for 1 to 2 cm) it at first becomes tapered then after receiving the pancreatic duct it ends in a dilated structure known as the ampulla (diverticulum papillae of Vater Pfuhl 1936) which according to Baldwin is co extensive with one half of the length of the papilla The ampulla varies in length (2 to 10 mm average 2 mm) and is ensheathed with smooth muscles (musculus proprius sphincter of Oddi) spastic contraction of which may cause reflux of the pancreatic excretion and of bile flow (Archibald 1919)

Incidence of an Ampulla Reports in the literature on the presence or the absence of an ampulla of Vater are strikingly at variance with each other whether ascertained from dissections of fresh or Formalin hardened specimens or by means of cholangiograms of patients or of excised organs injected with a contrast medium As far as gross anatomy

is concerned it should be relatively easy to determine in which case a dilatation or diverticulum exists at the lower ends of the common bile duct and the pancreatic duct However there are difficulties As emphasized by Rienhoff and Pickrell of Johns Hopkins University (1945) it is definitely a matter of opinion and definition as to whether an ampulla of Vater actually exists in those cases in which the septum between the two ducts extends within 2 mm of the apex of the duodenal papilla In *their studies of the nature of the* ampulla Cameron and Noble of the University of Minnesota (1924) call attention to the fact that the limit of error in taking measurements of the ampulla may amount to 3 mm or more thus accounting for numerous inaccuracies that exist in the literature regarding the presence or the absence of an ampulla and of its diameter measurements There is the added problem of the conditions in which the specimens were examined Because of shrinkage caused by a chemical agent measurements obtained from Formalin hardened specimens (cadavera) obviously are different from those made on fresh autopsy specimens or from calculations made by operative cholangiograms in patients or by x ray examination of autopsy specimens injected with a contrast medium Since the contrast figures given by different authors vary between 7 and 47 per cent Millbourn (1950) maintains that cholangiography *in vivo* cannot supply the exact conception of the actual frequency of type I presenting an ampulla or a common channel

According to Opie (1901) the ampulla which he observed in dissections while at Johns Hopkins University measured from less than 1 to 11 mm only in 30 of 100 specimens did it equal or exceed 5 mm In their study of 100 specimens Cameron and Noble (1924) did not list an ampulla of less than 5 mm After investigating 100 specimens at the Mayo Clinic Dardinski (1935) concluded that a true ampullary dilation within the papilla is present only in those cases in which the pancreatic and common bile ducts unite 5 mm or more from the outlet In the remainder both ducts are separated by a thin membrane formed by the adjacent walls of the two ducts In 51 per cent this membranous partition extended from the base of the papilla to the outlet so that the two ducts did not unite and no ampulla was *formed Recently Hughes and Kernutt* of Australia (1954) made similar observations for in 11 of their 30 Formalin hardened specimens a V shaped septum completely separated the common and pancreatic ducts so that no ampulla existed In 8 specimens the septum between the two ducts could be seen protruding through the papillary orifice

Naatanen of the University of Helsinki (1941) found an ampulla in two thirds of 100 specimens the remaining one third having separate openings of the ducts with a septal wall of 1 mm between them The average length of the ampulla was 6 mm with variations from 2 to 15 mm The average diameter of the ampulla was 4 mm with variations from 2 to 7 mm In 15 per cent the length and the diameter were the same and in 29 per cent the length was double that of the diameter The ampullary opening into the duodenum had a diameter of 3 mm the smallest opening being 1 mm and the largest 4 mm In the Japanese according to Nagai and Sawada (1925) the depth of the ampulla varied from 1 to 9 mm measured from its opening to its bottom The width of the bile duct varied from 3 to 10 mm that of the pancreatic duct from 2 to 7 mm

Rienhoff and Pickrell (1945) ceased to define an ampulla in those instances in which the septum separating the two ducts extended to within 2 mm of the

apex of the papilla The ampullae that they noted had an average diameter of 3 mm and measured from 3 to 14 mm from the apex of the orifice Mann and Giordano (1923) reported that in 76 per cent the average length of the ampulla was 2 mm in 14 per cent 3 mm in 2 5 per cent 4 mm and in 3 5 per cent from 5 to 10 mm Hughes and Kernutt (1954) state that, in their 30

TABLE 2 DISSECTIONS REVEALING THE PRESENCE OF AN AMPULLA (COMMON CHANNEL) OR SEPARATE ORIFICES FOR THE COMMON BILE AND PANCREATIC DUCTS*

INVESTIGATOR	NUMBER OF SPECIMENS	COMMON AMPULLA CHANNEL	PER CENT	SEPARATE ORIFICE	PER CENT
Schirmer (1893) (cited)	17	25	53	22	47
Letulle and Nattan Larrier (1898)	21	6	29	12	57
Opie (1903)	*100*	89	89	*11*	*11*
v Bungner (1903)	58	57	98	57	98
Ruge (1908)	43	32	75	7	16
Stracker (1909) (cited)	44	35	80	9	20
Baldwin (1911)	90	70	78	*20*	22
Belou (1915)	50	13	26	28	56
Mann and Giordano (1923)	200	90	45	62	31
Maeda (1924)	60	46	77	?	?
Cameron and Noble (1924)	100	74	74	26	26
Nagai and Sawada (1925)	58	52	90	5	9
Holzapfel (1930)	50	10	20	39	78
Nuboer (1931)	75	57	76	14	19
Cestari and Tantini (1933)	50	48	96	?	?
Couvelaire (1934)	25	8	32	17	68
Dardinski (1935)	100	49	49	51	51
Mehnen (1938)	449	248	55	170	38
Naatanen (1941)	100	67	67	33	33
Rienhoff and Pickrell (1945)	250	81	32	73	29
Howard and Jones (1947)	150	109	73	41	27
Hjorth (1917)	100	86	86	14	14
Sterling (1919)	50	18	36	32	64
Millbourn (1950)	200	171	85	18	9
Hughes and Kernutt (1954)	30	17	57	11	37
Totals	2 500	1 558	63	772	31

* The articles of all the listed investigators except the two marked cited were read personally by the author The task of assembling and interpreting the data as presented was indeed an arduous one fraught with many difficulties because of differences of methods descriptions and concepts Beginning with v Bungner's assertion that the pancreatic and bile ducts always open separately in a diverticulum of Vater of the papilla thus placing the samples in both columns (for an ampulla and for separate orifices) confusion reached its height with the assertion of Maeda that only two types of openings exist—to wit a type with a septum between the two ducts before opening into the diverticulum (16 cases) and a type without a marked diverticulum but still having a common opening (12 cases)

It is suggested that henceforth for uniformity of record the classification of openings as ascertained by Millbourn (1912) and Hjorth (1917) by the cholangiographic method be adopted These authors made x ray examinations of autopsy specimens after contrast injections into the bile and pancreatic ducts As illustrated their three types are as follows (1) pancreatic duct opens into common bile duct at a variable distance from the opening on the greater papilla of Vater in the duodenum (3 varieties of which 2 have an ampulla 8 per cent) (2) pancreatic and bile ducts open close by each other in the duodenum on the common major papilla without an ampulla (5 per cent) (3) pancreatic and bile ducts open in the duodenum at separate points without an ampulla (9 per cent)

specimens the average length of the ampulla was 18 mm the longest ampulla noted being 12 mm In 7 specimens the ampulla was but 1 to 2 mm In only 6 specimens was the common channel longer than 5 mm

Anatomically considered the concept that in the ampulla of Vater a structural arrangement exists whereby the common and pancreatic ducts are converted into a single communicating system is well established for most of the authors who investigated the problem in dissections found an ampulla to be present in the majority of their specimens the average of 2 500 dissections being 62 per cent as shown in the table on page 70 compiled from the literature by the author

Recent reports based on operative procedures and on operative cholangiographic studies especially in cases of acute pancreatitis afford substantial contributory evidence of the existence of a common passageway for the two ducts (Doubilet and Mulholland 1949 Cole and Grove 1952 Jones and Smith 1952 Kjaergaard of Denmark 1952) Complete absence of an ampulla was reported by Schirmer (1893) in 17 of 100 cases by Opie (1903) in 11 of 100 cases by Baldwin (1911) in 22 per cent of 90 dissections and by Hughes and Kernutt (1954) in 11 of 30 specimens According to Sterling (1949 1952) the ampulla does not exist as an anatomic structure in the adult at all the distal expended portion of the common bile duct being the caruncle or papilla of Vater

Vater s article on the orifice of the common bile duct was published in 1820 But what Abraham Vater Professor of Anatomy at Wittenberg originally described was a diverticulum (later known as the ampulla of Vater) which according to Hyrtle (1880) was not an ampulla at all but an elevation of the mucosa

Actually the first accurate description and illustration of the ampulla of Vater was made by Professor Simon H Gage of Cornell University (1878) in the cat and published in the *American Quarterly Microscopic Journal* in 1879 In his Figure 1 Gage illustrates the structure of the ampulla as seen in microscopic section to wit common bile duct pancreatic duct ampulla with villi circular and longitudinal muscle layers and the contracted opening of the ampulla which is at the summit of the papilla To familiarize readers with Gage s pioneer contribution the following excerpts are taken from his summary (p 178)

7 As the ductus choledochus and duct of Wirsung pass through the longitudinal muscular coat of the duodenum they are provided by it with a common and each with a special sphincter 8 The ductus choledochus and the duct of Wirsung empty into a common reservoir the ampulla of Vater situated between the muscular and mucous coats of the duodenum 9 The ampulla and the terminal part of the ducts of Wirsung and Santorini and the ductus choledochus are provided with valvular folds whose free edges are directed toward the orifices in each case 10 The structure of the mucous membrane of the ampulla is like that of the terminal part of the duct of Wirsung and the ductus choledochus and not like that of the duodenum hence it should be considered in the cat at least as an appendage of the ducts and not of the duodenal mucous membrane

Sphincter of Oddi

The long neglected sphincter of Oddi suddenly came into prominence with the contention of Westphal of the University of Frankfurt a M (1923) and of several other European clinicians and pathologists (von Bergman Kalk Schondube Lutkens Berg Schreiber) that pain in the right hypocondrium similar to that from gallbladder disease may be due to a spastic contraction of the sphincter of Oddi a condition known as biliary dyskinesia Other problems involving

the sphincter were (a) persistence of symptoms following cholecystectomy due to a spastic condition of the sphincter (b) reflux of bile into the pancreatic duct with subsequent hemorrhagic pancreatitis as a result of obstruction of the ampulla by spasm (Archibald 1912) edema tumor or stone (c) reflux of pancreatic juice into the biliary passageways with resultant cholecystitis when a common pathway for the two ducts became established in the ampulla and the latter became spastic and (d) arrival of the third era in the surgical treatment of gallstones which according to Lahey (1938) of Boston consists not only in the removal of the gallbladder (second stage the first being cholecystotomy) but also in opening (in 40 per cent of cases) the common bile duct investigating it for any residual stones lodged in the ampulla of Vater dilating the sphincter by means of the Backus dilator up to 9 mm and establishing internal drainage of bile by irrigation To these newer procedures may be added operative cholangiography first introduced in 1932 by Mirizzi of the Faculty of Medicine Cordoba Argentina as a method of disclosing calculi in the ductal system

Current major clinical and surgical problems accordingly need elucidation regarding the exact anatomy and the specific function of the intrinsic musculature of the bile and pancreatic ducts and of the ampulla Since nearly all texts of anatomy and surgery fail to give an adequate description of the anatomy of the sphincter of Oddi the following detailed account of it as ascertained by leading investigators is presented The work of Boyden and his co workers is especially emphasized as wax reconstruction models and a newly devised maceration technic were used to obtain their results[7] The startling new and strikingly different concept of Schreiber of the University of Frankfurt a M (1944)—viz that a sphincter of Oddi as usually conceived does not exist as a specific independent anatomic structure (closing mechanism) at all, and that in its stead the musculature of the lower extraduodenal choledochus and that of the ampulla of Vater should be regarded as a muscle complex (musculus complexus papillae duodeni) composed of and united by parts derived from the circular and the longitudinal muscle layers of the duodenum—will likewise be reviewed in detail

That a sphincter muscle comparable with the sphincter of the anus exists at the end of the common bile duct was first shown by Francis Glisson (1654) Regius Professor of Physick at Cambridge Reader in Anatomy in the College of Physicians at London and author of *Anatomia hepatis* (1654) A complete account of Glisson s concept of the sphincter mechanism as originally written in Latin (edition of 1681 Chapter

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[7] The Boyden birthday volume of the *Anatomical Record* (118 13–18 1954) contains a chronologic list of references to all of Boyden s publications Over 50 papers pertaining to the biliary apparatus especially the gallbladder are listed Topics investigated by Boyden and his co workers comprise (a) the pancreatic bladder and the gallbladder of the cat and the effect of a diet of egg yolk and cream on gallbladder evacuation (b) experimental expulsion of bile in animals aberrant biliary vesicles in man and domestic animals (c) the gallbladder in fasting (d) sex differences in contraction of the gallbladder (e) the cause of congenital absence of the gallbladder (f) the reaction of the gallbladder to stimulation of the gastro intestinal tract and the visceral nerves (g) double ductus choledochus (h) cholecystographic and fluoroscopic study of reactions to faradic stimulation of the stomach and the duodenum (i) Phrygian cap (j) evacuation in old age (k) pars intestinalis of the common bile duct (l) retardation of the gallbladder in pregnancy (m) the sphincter of Oddi in man and mammals (n) the origin of the ampulla of Vater (o) hypertrophy of the sphincter choledochus (p) the blood supply and the innervation of the choledochoduodenal junction in the cat (q) the effect of sectioning various autonomic nerves upon the rate of emptying of the biliary tract in the cat (r) the reaction of the human gallbladder and the sphincter of Oddi to magnesium sulfate (s) the rate of emptying of the biliary tract following section of the vagi or of all the extrinsic nerves (t) the gallbladder in patients with pernicious anemia with peptic ulcers and a few other topics

XVI) was published by Henrickson in the *Johns Hopkins Hospital Bulletin* (1898) and is given in translated form by Boyden in the *Anatomical Record* (1936) An exact evaluation of the Latin text shows that Glisson[8] correctly described the oblique course taken by the common duct through the tunics of the duodenum that he definitely stated that regurgitation of the intestinal content was prevented by ring like fibers which occupy not only the opening of the duct itself but also the whole oblique tract and that the sphincter contracted by spontaneous motion Glisson had no idea that the sphincter was concerned with regulation of bile flow into the intestine for he thought its sole function was to prevent a regurgitation of chyle into the common bile duct

Two hundred years later (1887) in an article of 6 pages published from the physiologic laboratory of the University of Perugia Italy Rugerro Oddi gave the first histologic description of the sphincter muscle at the end of the common bile duct designating the structure as the sphincter du choledoque He used the maceration technic of his chief Professor Marcacci who by placing tissue in a mixture of nitric acid glycerin and water had successfully isolated the smooth muscles of the mammary areola Oddi macerated duodenal tissue in this mixture for 3 to 4 days and as an additive measure studied the sphincter in microscopic sections The animals investigated comprised the following cat dog pig sheep horse ox and birds especially the pigeon and the chicken Oddi did not investigate the sphincter muscle in man although he regarded it to be like that of the lower animals for in a few sections of human material he found sphincter fibers at the end of the choledochus

Oddi reported that the sphincter muscle varied considerably in different animals especially in birds being most typical in dog and sheep While the sphincter muscles (circular fibers) could be lifted off the choledochus in macerated specimens serial sections showed its true structural arrangement for they

demonstrated clearly the existence of a muscle ring surrounding that part of the choledochal canal that traverses the intestinal tunics and excludes entirely the possibility that there is here merely a simple ring of the circular muscle layer of the intestine

A complete account of Oddi s article is given by Henrickson in his literary review of the sphincter In view of the clinical and the pathologic importance of the sphincter muscle and as a ready reference for investigators the following conclusions arrived at by Oddi as a result of his studies are quoted from his paper

1 Il existe une disposition musculaire a sphincter speciale a l embouchure du canal choledoque dans l intestin 2 Ce sphincter est constitute de fibres musculaires lisses et en grande partie independantes des tuniques musculaires de l intestin 3 La fonction probable de cette disposition a sphincter est de rendre intermittant et de regler l ecoulement de la bille dans l intestin 4 A l embouchure du conduit de Wirsung il existe egalement une disposition musculaire a sphincter 5 Cette disposition a sphincter permet de se rendre compte de quelques affections morbides dont la cause n avait pas ete encore determinee cliniquement

It should be noted that Oddi called attention to the fact that a comparable sphincter existed about the pancreatic duct in man that removal of the gall bladder is followed by dilation of the bile ducts and that he was able to demonstrate the resistance of the sphincter

[8] In writing about the annular fibers of the common bile duct Glisson in his *Anatomia hepatis* (1681) stated "Denique regressus omnis in ductum communem praepeditur a fibris annularibus quae non modo orificum ipsum sed et totum obliquum tractum obsident" (ita Oddi 1887)

He was the first to suggest that dysfunction (spasm) of the sphincter may account for the morbid conditions of the bile tract later known as biliary dyskinesia (Westphal 1923) about the nature and the true significance of which there is still considerable controversy today (Cole and Grove 1952) In a later contribution Oddi (1894) claimed that the sphincter has a special spinal cord ganglion center located at the level of the first lumbar segment it being regarded as an inhibitory reflex mechanism

The first comprehensive description of Oddi s sphincter muscle in man was made by Henrickson of Johns Hopkins University (1898) As a student of the American anatomist Lewellys Barker he investigated the musculature of the entire extrahepatic passageways in dog rabbit and man As methods he used the maceration technic of Marcacci and that of Ranvier but he relied mostly on microscopic serial sections In Figure 38 of his paper Henrickson illustrates the sphincter as observed in man The common bile duct and the pancreatic duct of Wirsung are illustrated passing through a simple separation of the fibers of the outer longitudinal muscles Fibers arising from the outer longitudinal muscle coat run up on the common bile duct where gradually they become less abundant and then disappear This arrangement is bilateral Some fiber bundles form an independent ring of muscles around the common duct between it and the duct of Wirsung The muscle fibers that run almost entirely around the duct of Wirsung as they approach that side of the pancreatic duct nearest to the common bile duct turn abruptly and run upward on the duct of Wirsung in a longitudinal direction Henrickson s original illustration of the sphincter of Oddi is reproduced in Morris s textbook *Human Anatomy* (1953) in Figure 1067

Helly, of Vienna (1899) followed Henrickson in being one of the first to confirm Oddi s concept of the sphincter His paper contains three colored illustrations of the histology of the human sphincter Its musculature is composed not only of circular but also of longitudinal and oblique fibers Only occasionally was the sphincter muscle found to be connected with the musculature of the duodenum Helly likewise found muscle fibers about the pancreatic duct In his opinion, the sphincter muscle not only was a sphincter but also could pull in the plica longitudinalis

Subsequent major anatomic investigative studies on the sphincter of Oddi and the opening of the common duct comprise those of Mann (1919 1920 1923) Mann Brillman and Foster (1920) Mann and Giordano (1923) Matsuno (1923) Westphal (1923 1931) Nagai and Sawada (1925) Higgins and Mann (1926 1935), Higgins (1927 1928) Porsio (1929) Nuboer (1931) Cestari and Tantini (1933) Dardinski (1935) Boyden (1936 1937 1940 1941) Schwegler and Boyden (3 papers 1937) Kreilkamp and Boyden (1940) Schulze and Boyden (1943) and Schreiber (1944) The anatomy of the musculature of the gallbladder and the bile ducts has been investigated extensively by Berg (1917–22) Westphal (1923) Haberland (1926) Pfuhl (1927) Lutkens (1928) and Schreiber (1940)

To give but a cursory survey of the works of the listed authors would entail a text beyond the scope of this atlas The skepticism regarding the nature and even the existence of the sphincter of Oddi (Auster and Crohn 1922) centered about three points to wit (1) the difficulty of demonstrating its independent histology (2) the difficulty of separating its action from that of the musculature of the duodenum that surrounds it (3) the uncertainty as to its mode of control whether by the nervous

system (sympathetic and parasympathetic) by hormones or by both Today the sphincter of Oddi is regarded not only as an occluding mechanism but also as an ejaculatory one as well (Westphal 1931 Nuboer 1931 Pfuhl 1932)

The anatomy of the sphincter of Oddi in man has been well established by Henrickson Helly Matsuno Porsio Nagai and Sawada and especially by Boyden and his co workers The conventional concept of it however more recently has been altered substantially by Schreiber (1941) who not only doubts the appropriateness of the designation sphincter of Oddi as a specific entity but also regards the anatomy and the function of the musculature at the end of the choledochus to be intimately connected with that of the circular muscle layer of the duodenum In this interpretation he follows to a large extent the concept expressed 20 years previously by Dardinski of Georgetown University (1935) who maintained that the flow of bile appears to be controlled by the tonicity of the inner circular muscle of the intestine to which muscle fibers from the base of the papilla extend and interdigitate The illustrations of Schreiber and of Dardinski on this point are strikingly similar

Higgins of the Mayo Clinic (1928) gave the first data on the phylogenetic origin of the thick musculature at the end of the common bile duct as seen in fish—the bullhead (*Ameiurus nebulosus*) Peristaltic waves which began in the fundus of the gallbladder were observed to extend all the way down to the bile tract in the duodenum In the guinea pig Higgins (1927) likewise showed that the evacuating mechanism of the gallbladder is not dependent on intestinal movements Bile passes into the duodenum by the successive contraction of the gallbladder the sphincter mechanism and the pouch at the lower end of the common bile duct Higgins noted that rhythmic pulsations pass over the peculiar bile evacuating mechanism at the lower end of the common duct The waves of contraction passed over it in a cephalocaudal direction He got active pulsations of the contractile pouch when there was no visible sign of peristalsis proving definitely that the greater part of the musculature of the sphincter mechanism is independent of that of the duodenal musculature Previously Higgins and Mann (1926) had shown that in dog cat and guinea pig the emptying process of the gallbladder does not take place in animals under ether or urethan anesthesia but must be done by the use of some local anesthesia Years later Higgins and Mann (1935) showed that brief electric stimulation of the intramural part of the common bile duct that had been dissected away from the duodenum in the dog induced a contraction which stopped the flow of fluid at a pressure greater than the secretory pressure of the liver or that produced by the contraction of the gallbladder Mann Brimhall and Foster (1920) made a study of the comparative anatomy of the bile tract in 15 species of animals (some with a gallbladder some without one) They concluded that there was no relation between the termination of the common duct and the absence or the presence of a gallbladder nor was there any relation between the size of the bile duct and the point of entrance into the duodenum in species with a gallbladder as compared with those without one

Boyden of the University of Minnesota (1937) made a comparative embryologic study of the pars intestinalis of the common bile duct in four mammalian species (opossum dog guinea pig and man) and reported decided variations in its intrinsic musculature The most striking feature in the opossum was the complete separation of the intrinsic musculature from that of the duodenal wall throughout the intramural course of the

common duct and the fact that the ampulla lies wholly outside of the intestine The dog has no ampulla of Vater and therefore no musculus proprius since even in the embryo the two ducts open separately into the duodenum In the guinea pig most of the ampulla has been taken up into the intestinal wall and its intrinsic musculature is blended so intimately with the circular muscles of the intestine that in the adult the two layers cannot be differentiated except at the two ends of the ampulla In man the sphincter of Oddi has three characteristic features to wit (1) its relative freedom from intestinal interference due to the configuration of the window (fenestra) in the duodenal musculature through which it passes (2) the retrogression of the ampullary segment (3) the development of a special contracting mechanism just above the point where the bile duct joins the ampulla of Vater In the chimpanzee Boyden (1940) found the sphincter ampullae to be better developed than in man

In an investigation conducted at Vienna Matsuno of Nagoya Japan (1923) presented an extensive description of the musculature of the ductus choledochus and of the sphincter around the diverticulum of Vater He found the circular musculature of the sphincter to be in direct continuity in many places with the musculature of the duodenum being distinguishable from the latter only by the fact that it had less wide muscle fibers The length of the stretch of the circular muscle band varied from 5 to 10 mm The more one receded from the summit of the papillae the smaller became the muscle ring and the more markedly it became interrupted Toward the liver muscle fibers became less and less numerous and eventually the entire wall of the choledochus became free of muscle fibers these being replaced by connective tissue[9]

Nagai and Sawada of the Imperial University of Kyoto (1925) were the first to study the sphincter of Oddi in the Japanese They classified the constituent muscle fibers into circular longitudinal and oblique the latter being of two types viz those running from right to left or vice versa The depth of the ampulla varied from 1 to 9 mm the width of the bile duct varied from 3 to 10 mm the width of the pancreatic duct varied from 2 to 7 mm At the ampulla the transverse layer of muscles was always well developed but as one proceeded upward or downward it became weaker At the point where the bile duct penetrated through the circular muscle layer of the gut its musculature had some relation with the duodenal circular muscles but after the passage was established it constituted an independent system being separated from the intestinal musculature by connective tissue Functionally the longitudinal and the oblique fibers pull the papilla of Vater upward in order that the Oddi muscle can accomplish its sphincteric action

In a study of the physiologic anatomy of the gallbladder Pfuhl of the Anatomical Institute of Greifswald (1927) maintains that the muscularis mucosae of the gut is continuous in the sphincter of Oddi and into the muscularis of the gallbladder (Helly) Toward the tunica muscularis the sphincter is separated by submucosal tissue Only isolated bundles proceed from the gut musculature to that of the closing sphincteric musculature

Porsio of the University of Palermo Italy (1929) investigated the sphincter

[9] Two of Matsuno's colored illustrations of the *diverticulum of Vater are reproduced as Figures 21 and 22 in the chapter on the liver written by Pfuhl (192)* for the *Handbuch der Mikroskopischen Anatomie des Menschen*

of Oddi in babies and in adults of various ages During the first year of post natal life the sphincter was found to be poorly developed it still being in the formative stage It consisted of weak layers of circular muscle fibers one surrounding the choledochus another the pancreatic duct and one surrounding both ducts The muscles which embraced the choledochus extended from the region where it penetrated the duodenum to the ampulla of Vater Since the sphincteric muscles received numerous and large fibers from the circular muscle layer of the gut especially at point of penetration of the choledochus the sphincteric system was regarded as a true and *proper emanation* of the circular muscle layer In the adult the sphincter has the same disposition it had at the end of the first year It is however denser and longer extending upward to end at a certain distance from the point where the choledochus penetrates the wall Downward it ends where the ampulla of Vater enters the duodenum The sphincter maintains its intimate connection with the circular muscle layer and in addition has dilator fibers

Nuboer of the University of Utrecht (1931) investigated the gross anatomy and the histology of the extrahepatic bile passageways in 75 specimens In most cases (76 per cent) he found an ampullary widening in which the pancreatic duct likewise emptied The sphincter of Oddi was found to be composed of circular longitudinal and oblique fibers Part of it was in direct connection with the muscularis mucosae layer of the duodenum The sphincter has not only a closing function but also one of ejaculation this being accomplished by the longitudinal part of the sphincter muscle

Innervation of the Sphincter The innervation of the sphincter of Oddi like that of the entire biliary tract is far from being solved In texts of anatomy and physiology according to Auster and Crohn of Cornell University (1922) it is presumed that the vagus contains motor fibers for the sphincter and the inhibitory fibers for the gallbladder The same stimulus that traverses the splanchnic system to cause contraction of the gallbladder would simultaneously relax the sphincter or when traveling through the vagus would contract the sphincter and relax the gallbladder This notion of a contrary innervation and inhibition was conceived by Meltzer (1925) But this crossed system of innervation for the gallbladder and the sphincter—i e a system which would cause a contraction of the gallbladder simultaneously with a dilation of the sphincter and vice versa—is not agreed upon generally by physiologists and repeatedly has been proved to be erroneous

That the biliary system has an abundant intrinsic and extrinsic nerve supply including ganglion cells was shown clearly by Dogiel as early as 1895 Using a methylene blue technic he found a rich main plexus in the outer connective tissue layer of the gallbladder and the bile ducts It was composed mostly of Remak fibers the myelinated fibers being few in number Ganglion cells occurred singly and in groups at the peripheral regions they were bipolar and in the center they were multipolar Kuntz of St Louis University (1929) maintains that if Dogiel ganglion cells exist in the wall of the gallbladder and the bile ducts they belong to the parasympathetic system and probably are components of the vagus In his opinion the musculature of the biliary system responds to parasympathetic and sympathetic stimulation essentially in the same manner as the musculature of the gastrointestinal tract

Harting of the University of Bonn (1930) using only animal material impregnated with the silver method noted

that most of the nerves to the gallbladder came from the celiac ganglion and followed the cystic artery The parasympathetic nerves came from the vagus In the adventitia of the gallbladder the nerves *formed a main plexus resembling* the Auerbach plexus The muscularis likewise contains a plexus End nets in the mucosa reach the epithelial layer and the basal membrane Harting found ganglion cells in all layers of the gall bladder Everywhere the nerves were connected with one another forming a *closed syncytium the physiology of* which naturally could not be determined on an anatomic basis For detailed and extended information regarding the nervous influence on the gallbladder and the bile ducts as ascertained by physiologic experiments the reader is referred to the excellent summary made thereof by Kuntz (*The Autonomic Nervous System*, Philadelphia Lea & Febiger 1945)

Dyskinesia In 1923 Westphal of the University of Frankfurt a M published a pioneer work based on clinical and roentgenologic studies in which he maintained that nervous spasm of the sphincter of Oddi can cause primary obstruction of the biliary passageways In hypermotility neuroses the gallbladder and the bile ducts work versus a spastic con*dition of the sphincter of Oddi while in* hypomotility neuroses there is present an atony—i e a relaxation of the gall bladder and the sphincteric musculature In short all primary causes of stasis are due to a neurosis of motility Both hypermotility and hypomotility may become a general dyskinesia of the bile passages with a mixture of tonus decrease and increase of action Berg of Stockholm followed this trend of thought with the contention that reflex influences on the sphincter of Oddi are the primary causes of gallstone formation Lutkens of Berlin supported Westphal and in addition added an extra sphincter—viz that of the neck of the gallbladder the so called sphincter collum cysticus

Westphal maintained that whereas the sphincter of Oddi is an independent structure it is much more than a sphincter He distinguished three segments in its constitution (1) a beginning part (antrum) (2) a middle section (portio duodenalis) and (3) an end piece (pylorulus) The antrum connected with the muscularis of the duodenum plays an important role in eliciting bile flow in the duodenum the pylorulus connected with the duodenal muscularis mucosae, and situated at the transition of the papilla in the duodenum is innervated by the sympathetic system and has essentially a closing function The ampulla is comparable with the pyloric end of the stomach for it undergoes peristalsis

Westphal stated that with electric stimulation of the vagus the splanchnics or the celiac ganglion he never obtained peristaltic movement in the gallbladder and the bile passages but that at times movements could be seen about the opening of the choledochus—i e in the sphincteric region—these being especially visible in the rabbit and the guinea pig Light electric stimulation of the vagus caused contraction and narrowing of the gallbladder with apparent widening of the portio duodenalis of the common duct Strong stimulation of the vagus caused a lingering contraction of the sphincteric territory of the choledochus with partial or total sphincteric spasm stasis of bile widening of the upper choledochus and gradual increase of the gallbladder Sympathetic stimulation caused an increase in the duodenal part of the common duct but effected no outflow of bile Later Westphal and Schondube (1927) reported that the relative independence of the sphincter of Oddi from the muscle function of the duodenum could be determined readily by vagal stimulation in the rabbit and the

cat where the sphincteric mechanism is not covered by pancreatic tissue

In his lengthy article Westphal calls attention to a frequently observed phenomenon—viz that after cholecystectomy the tone of the closing mechanism of Oddi is increased so much so as to give rise to a passive widening of the large bile ducts and of the cystic stump This passive widening of the biliary ducts may account for the *neoformation of small gallbladders as previously observed* by Kehr Haberer Clairmont Stubenrauch Florken Rost and Walzel These neoformed gallbladders may reach a length of 8 cm Usually they are smaller being 3½ to 4 cm in length Pear shaped they may contain from 3 to 8 cc of bile [10]

Cestari and Tantini of the University of Padua (1933) maintain that the intraparietal part of the common duct is supplied by autonomic nerves derived from two plexuses—viz a deep one situated between the two muscle layers and a superficial one located in the submucosa Schulze and Boyden (1943) showed that the extrinsic nerves to the choledochoduodenal junction are mediated through two pathways viz the gastroduodenal nerve and the gastroduodenal plexus It may be noted that Oddi found ganglion cells in the sphincteric musculature these being present at branching points of the nerves Dardinski (1935) gave a brief description and illustration of the nerves he encountered on the papilla of Vater dissected under microscopic vision

Embryologic Considerations The embryonic development of the sphincter of Oddi was investigated by Helly (1900) Broman (1913) Reitz (1917) and in particular by Schwegler and Boyden of the University of Minnesota (1937) In view of the comprehensive nature of the work of the latter authors a presentation of their findings is hereby presented

Schwegler and Boyden investigated the mode of development of the intramural (intraduodenal) part of the common bile duct the ampulla of Vater and the sphincter of Oddi for the entire prenatal period in 11 serially sectioned human embryos and fetuses Four critical stages (15 18 33 115 mm specimens) were selected for reconstruction in wax of older fetuses (365 430 525 mm) graphic reconstructions were made In their report (3 papers) the authors state that the terminal ending of the bile duct is associated with a definite bend in the fetal descending duodenum the biliary flexure (sometimes persistent in the adult and visible in roentgen films) immediately above or below which the ampulla empties In its primitive condition the ampulla is nothing more than a long hepatopancreatic duct which extends the entire length of its oblique passage through the intestinal wall As such it acquires two openings into the duodenum one superior which opens into the dextral cavity and one inferior which opens into the sinistral cavity of the primitive duodenum the cavities being formed through the coalescence of vacuoles Later (18 mm) when the two duodenal cavities fuse the lower orifice of the duodenum is suppressed but may persist thereby accounting for the mode of origin of the double orifice of the ampulla (usually 1 mm apart)

The primitive long ampulla undergoes regression i e the point of junction of the bile and pancreatic ducts

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[10] Westphal s article of 1923 (1[illegible]5 pages) is well worth reading In addition to summarizing opinions regarding the muscle function the innervation and the pathology of the biliary passageways it contains a report of his own investigations in animals on the various types of stimulants used (electric pharmacologic through pilocarpine adrenalin atropine morphine) on the results of an artificially produced cholecystitis in rabbits with a quantitative increase of the musculature of the sphincter of Oddi 3 months after injection of duodenal content and on observations made on patients in relation to pain symptoms and the associated viscero visceral reflexes thereof (*Ztschr f klin Med* 96 2[illegible]-150 1923)

recedes from the window in the intestinal wall into the submucosa until at term it is situated midway between the tunica muscularis and the end of the papilla Ultimately the ampulla becomes reduced to a small chamber the primary function of which is the production of valvules (wrinkles of the lining epithelium) that guard the orifice of the bile and pancreatic ducts thereby preventing regurgitation of intestinal content

The sphincter of Oddi or the musculus proprius which surrounds the intestinal part of the bile duct (bile duct ampulla and three sides of the pancreas) *takes origin in situ from mesenchymal cells* which at the 26 mm stage arrange themselves concentrically around the common bile duct and the zone of junction of the bile and pancreatic ducts *The musculus proprius is not an emanation from the tunica muscularis of the duodenum as claimed by Porsio (1931) but is an independent formation appearing 4 weeks later than the duodenal muscle* A ringlike sheath of fibers which surrounds the bile duct from the choledochal window to the junction of the bile and pancreatic ducts and which attains its maximal development just before it reaches the ampulla constitutes the sphincter choledochus which *independently of the surrounding intestinal muscle* through its contraction causes filling of the gallbladder during intervals between meals and which when overstimulated gives *rise to biliary dyskinesia* or dyssynergia This preampullary circular muscle band is essentially the sphincter of Oddi The muscle which ensheaths the ampulla (sphincter ampullae) because of the shortness of this segment offers little resistance to the flow of bile or pancreatic juice The sphincteric action of the circular fibers is doubtful for few fibers completely encircle the duct

The interval between the bile and pancreatic ducts is covered by two rows of longitudinal fibers placed anteriorly and posteriorly Cranially they run up along the *bile and pancreatic ducts to* extraduodenal levels giving off branches to the choledochal window Caudally they end in fibers some of which run in the plica longitudinalis others encircle the pancreatic side of the pancreatic duct and the ampulla and still others the mucosal side of the bile duct and the ampulla Contraction of the longitudinal fibers shortens the different segments of the pars intestinalis thus facilitating the discharge of *bile* and pancreatic juices

Present Opposing Concepts of the Anatomy of the Sphincter of Oddi

Two diametrically opposed concepts of the anatomic composition of the musculature which he calls the musculus *choledochal sphincter* exist today (a) that of the American anatomist Boyden who regards the muscular mass at the choledochal junction as an *independent* proprius and (b) that of the German anatomist Schreiber who considers the same muscular aggregate to be the musculus complexus papillae duodeni a derivative (i e sheared off) yet continuous portion of the circular and partly of the longitudinal muscle layers of the duodenum In this sense Schreiber's muscle mass constitutes a muscular mechanism entirely foreign to what anatomists *and surgeons used to consider to* be the sphincter of Oddi which according to Schreiber does not exist as a specific entity at all

How one asks with all modern technical equipment of microscopes differential staining of serial sections demonstrations with wax reconstruction models findings with diverse maceration technics as observed in microscopic dissection and after varied physiologic and

pharmacologic experiments can anatomically considered such two opposing views currently be advanced To the surgeon advised in the literature or by lecture to do a resection (sphincterotomy) of the sphincter of Oddi for biliary dyskinesia or stenosis of the sphincter this is a serious and baffling problem No wonder that Cole and Grove of the University of Illinois (1952) made this statement

> There is great controversy as to whether or not a true dyskinesia or spasm of the sphincter of Oddi exists We are convinced that dyskinesia exists but frankly have not seen any patients which could definitely be so diagnosed

Since obviously both views of Oddi's sphincter cannot be correct the error must lie in the mode of technic and in the interpretation of the data upon which the respective concepts of its constitution are based

1 The Musculus Proprius of Boyden

As with any other adult structure constitutional variations are to be expected in the composition of the sphincter of Oddi—i e in the intrinsic musculature of the bile and pancreatic ducts and of that of the ampulla of Vater The major investigative work on this phase of the problem was made by Kreilkamp and Boyden of the University of Minnesota (1940) in an examination of 25 autopsy specimens treated with a maceration technic (20 per cent nitric acid) The following is a summary of their findings

At the choledochoduodenal junction there is a gridiron shaped aperture through which the bile duct and the pancreatic duct enter the wall of the duodenum The aperture consists of a lengthwise hiatus in the longitudinal muscles of the gut superimposed on a transverse eye shaped cleft (fenestra) in the circular muscle layer Bands of muscle fibers connect the ducts to the margins of the hiatus and the fenestra They pass from the upper margin of the fenestra to blend with the fibers on the deeper surface of the longitudinal muscles of the gut or with the deep side of the circular muscles forming the lower margin of the window These muscle bands are postnatal expansions and tend to fill in the clefts—i e they camouflage the aperture The bands comprise two types (1) reinforcing fibers that reinforce the corners of the window thereby preventing its expansion by splitting (2) connecting fibers that attach the major papilla or ducts to the tunica muscularis of the gut and serve to erect the papilla The gridiron arrangement of the muscle bundles at the duodenal window is of interest only in respect to the shape and the size of the aperture these determining the gauge of the calculi that can enter the wall

Variations of practical significance are to be found only in the intrinsic muscles of the ducts and the ampulla Collectively they constitute the sphincter of Oddi and comprise the following muscle groups (1) Two longitudinal fascicles that respectively considered run anteriorly and posteriorly lengthwise of the papilla in the interval between the two ducts *and that serve to shorten and* erect the papilla (2) The sphincter choledochus an annular sheath of muscle fibers 1 cm or more in length that surrounds the common bile duct from a position just outside the window (fenestra) to its junction with the pancreatic duct It constitutes the most important part of the musculus proprius (sphincter of Oddi) for it obstructs the flow of bile causing it to back up into the gall bladder in the intervals between meals Spasm of this muscle may give rise to biliary dyskinesia (3) The sphincter pancreaticus an annular sheath found around the pancreatic duct just before

the latter joins the bile duct and occurring only in about one third of adults (1) The *sphincter ampullae* a more or less developed annular sheath that begins just before the junction of the ducts and *continues down around the ampulla* when the latter is present As a well defined sheath, it occurs only in one *sixth of adults* Spasm of this sphincter may cause reflux of pancreatic juice into the bile tract or vice versa of bile into the pancreatic duct

The sphincter choledochus is so situated that during fasting it retains the bile versus the secretory pressure of the liver causing the bile to back up in the gallbladder where it becomes concentrated by the mucosa After the ingestion of food the sphincter choledochus relaxes and the gallbladder contracts with the result that in from 7 to 15 minutes concentrated bile reaches the duodenum The longitudinal fascicles have the function of shortening the intramural part of the ducts thereby facilitating the flow of bile into the duodenum *When markedly developed the sphincter ampullae by spastic contraction can create a common continuous channel through which the contents of one duct may pass into the other* In separate investigative studies Boyden showed that (1) during pregnancy the tone of the sphincter is increased thereby delaying the discharge of bile after meals (2) in children the rate of evacuation of the gallbladder is faster than in early maturity and (3) in patients with peptic ulcers the gallbladder discharges its bile more rapidly than under normal conditions In 1923 Boyden was the first to demonstrate that of all ingested foods *egg yolk and milk cream are the most pre eminent in bringing about a rapid contraction of the gallbladder and relaxation of the sphincter of Oddi* Among substances that have been found to give temporary relief for the spasm of the sphincter of Oddi are egg yolk (Boyden) amyl nitrite and nitroglycerin (Butsch McCowan and Walters 1936) Hydrochloric acid applied to the papilla emotional disturbances and pain can induce a sphincteric spasm (Doubilet and Mulholland 1948) The pain that accompanies the spastic closure of the biliary outlet definitely has been shown to be due not to the spasm of the duodenum but to the contraction of the sphincter of Oddi itself (Bergh and Layne 1940)

2 *The Musculus Complexus Papillae Duodeni of Schreiber*

In 1941 Schreiber of the Department of Anatomy of the University of Frankfurt a M published a work in which he maintained that the conventional concept of the sphincter of Oddi is not the correct one and accordingly the term should be dropped Since the muscle complex in the wall of the lower extraduodenal choledochus and the papilla of Vater are connected intimately and continuous with the circular and partly with the longitudinal muscle layers of the duodenum and since its activity is conditioned and in unison with the peristaltic movements of the duodenum producing a rhythmic emptying of the gallbladder he designated the muscular elastic mass as the *musculus complexus papillae duodeni* Taken as a functional unit *the muscle complex constitutes an interplay or readjustment mechanism (Nachstellvorrichtung) whereby the biliary passages are constantly kept filled and whereby only a small amount of bile enters the duodenum at one time*

Schreiber's conclusions are based on an examination of the sphincter muscle of man as seen in gross dissection with the aid of a magnifying glass and as confirmed in a microscopic study of longitudinal and cross serial sections According to Schreiber from sectioned material alone one can never ascertain the true anatomy the spatial arrangement and

the significance of the musculature that surrounds *hollow organs* like the gall bladder the vagina and the veins With these organs a combined method of investigation (i e a macromicroscopic study) enabled him to arrive at the correct interpretation of the pertaining musculature

As evaluated with the dual method of study Schreiber claims that the circular musculature of the duodenum immediately above the region where the choledochus goes through it obliquely becomes markedly increased and is in direct continuity with the musculature of the choledochal wall The longitudinal musculature of the duodenum however ceases to be a complete envelope For a long stretch from the point where the choledochus passes through it it becomes split into individual fiber bundles After removal of the mucosa of the duodenum the circular muscles of the latter can be seen clearly and when the mucosa of the papilla is removed a network of extremely fine muscle fibers may be observed in the mucosa (submucosa) These fine muscle fiber bundles correspond to the muscularis mucosae of the duodenum but are much too fine to have a function ascribed to them in regard to the activity of the papillary wall The true musculature of the latter appears after the removal of the mucosa

The size and the shape of the papilla vary considerably Some reach the level of the mucosa others have the shape of a tenpin The porus papillaris is predominately clefted showing irregular folds and in many instances protrusions of the mucosa The form of the plica longitudinalis depends on the length of the intramural (intraduodenal) part of the bile duct The longitudinal types measure from 13 5 to 19 mm the shorter vary from 9 to 12 mm The plica suprapapillaris corresponds to the region where the circular muscle layer is traversed by the choledochus

The musculus complexus papillae duodeni is composed of the following parts

1 *The M sphincter basis papillae* It constitutes the strongest part of the system and consists chiefly of strands of muscle fibers derived from the circular muscle layer of the duodenum which crisscross the choledochus at a point where it penetrates the circular muscle layer and then partly turns back into the circular muscle layer on the contralateral side In addition it is made up a sling of muscles that embraces the exact penetration point of the choledochus

2 *The M dilatator papillae* It is composed of a network of longitudinal muscle fibers on the papilla that are partly split off portions of the M basis papillae partly derivatives from the wall musculature of the choledochus and partly sheared-off portions of the longitudinal muscle layers of the duodenal wall The fibers accompany the upper and under sides of the papilla throughout its entire length Those on the upper side are derived from the M sphincter basis (i e the circular muscle layer) those on the under side are composed of strands from the circular layer and of sheared off fibers from the longitudinal muscle layer of the duodenum Rich in musculo elastic elements this muscular network comprises fibers that spread out into the mucosa where they surround glands and blood vessels abundantly present in the longitudinal folds of the mucosa of the diverticulum of Vater In fact the tissue relations between glands and muscle fibers here are so intimate as to resemble those observed in the prostate gland

3 *The M sphincter pori papillaris* It is a very weak circular component that surrounds the porus papillaris It is made up of long thin slender muscle bundles that are partly connected with split off portions of the M dilatator papillae and partly independent elements

It may be a derivative of the muscularis mucosae.

4. *A longitudinal muscle* net that accompanies the extraduodenal choledochus for 1 to 2 cm. As a musculo-elastic system it is especially well developed in the side walls and has direct relations to the longitudinal muscle layer of the gut. Ultimately it ends by becoming continuous with the elastic network of the choledochus devoid of or poor in muscle fibers.

Schreiber maintains that it is difficult to decide which one of the three sphincters should be called the "sphincter of Oddi." He calls attention to the fact that Dardinski (1935) had restricted the sphincteric mechanism to the muscle fibers about the base of the papilla, a portion which Schreiber regards as the M. sphincter basis. If Oddi's sphincter is to be regarded as a mechanism whereby the lumen of the bile duct is closed, preventing entrance of intestinal content into the choledochus, then the M. sphincter pori papillaris is the one involved. *Taken as a functioning unit, the musculus complexus papillae duodeni cannot be regarded as an independent sphincter at all, for its working mechanism is always tied up with the motor activity of the duodenal musculature. Contractions of the circular muscle layer of the duodenum during peristalsis are prolonged on the muscular strands of the papilla.* Through a contraction of the M. sphincter basis papillae a closure of the intradural choledochus is effected versus the extraduodenal part thereof. Contractions (i.e. shortenings) of the M. dilatator papillae dilate the wall of the papilla, express the contents of the mucous glands of the choledochus and expel the bile content of the papilla into the duodenum. For the latter phase of the process the M. sphincter pori papillaris must relax. With relaxation of the circular musculature of the duodenal wall the M. sphincter basis and the M. dilatator papillae likewise relax, allowing filling of the diverticulum of Vater. The longitudinal folds of the mucosa become unfolded and through a change in their configuration by swelling close the porus papillaris, assisted therein by the M. sphincter pori papillaris. Through ever changing fillings and swellings the veins in the neighborhood of the papilla may assist in the opening and the closing of the porus.

The closing mechanism at the papillary orifice is comparable with that occurring in the anal closure (Stieve), in the urinary bladder (Heiss) and in the vagina (Schreiber). The pressure to which the closing mechanism is exposed can at most be equal to that exerted by liver secretion which lies between 250 and 300 mm. of water and accordingly is not very high. By this simple mechanism the rhythmic emptying of the gallbladder into the duodenum in consecutive small amounts is accounted for on both an anatomic and a functional basis. In support of his concept of the choledochal sphincteric mechanism Schreiber presented several roentgenograms depicting various phases of its activity.

3. *Musculature of the Duodenal Papilla According to Dardinski*

In substantial agreement with Schreiber's concept of the anatomy and the functional activity of the major duodenal papilla is that proposed by Dardinski of Georgetown University (1935) 20 years previously. While doing postgraduate work at the Mayo Clinic he investigated the duodenal papilla in 100 necropsy specimens. Like Schreiber he used a combined technic of macroscopic dissection and examination of microscopic slides. The dissection was carried out under water with the aid of fine surgical (eye) instruments on 30 fresh specimens that previously had been treated for several days (42 to 72 hours) with the

Marcacci maceration technic (equal parts of concentrated nitric acid glycerin and water) In contrast with Schreiber who failed to study the relations of the terminal portion of the pancreatic duct to the common duct Dardinski took this point into consideration in every case and in addition ascertained the frequency of a true ampullary dilatation of the papilla

Dardinski reported that in 51 cases the pancreatic and bile ducts emptied separately in the tip of the papilla In 12 cases both ducts united 1 mm from the outlet in 5 cases 2 mm from the outlet in 12 cases 3 mm in 10 4 mm in 4 5 mm and in 1 1 cm from the outlet Only in one case did both ducts open separately into the intestine A true ampullar dilation in the papilla was present only in those cases in which the two ducts united 5 mm or more from the outlet In the remaining cases both ducts were separated by a thin membrane formed by the adjacent walls of the pancreatic and bile ducts which extended from the base of the papilla to the point where the ducts united In 51 cases (51 per cent) the membranous partition extended from the base of the papilla to the outlet so that the two ducts did not unite and accordingly no ampulla was present

Like Schreiber Dardinski began the study of the musculature of the papilla with the removal of the mucosa the submucosa and the connective tissue containing nerves blood vessels and glands When these tissues are removed the papilla is seen lying in a trough formed by the inner circular muscle layer of the duodenum to which it is attached by connective tissue The terminal part of the common bile duct is divisible into an intraduodenal and an extraduodenal part The dividing line between these portions can be seen readily it corresponds to the level at which the intestinal musculature surrounds the intramural part of the duct to produce its greatest constriction at this point The extramural part of the common duct is smooth and contains many large pits which constitute the outlet of the sacculi found in the common duct

The intramural part of the common duct is composed of numerous longitudinal folds that vary in length from 2 to 4 mm and in width from 2 to 3 mm The tip or end of each fold fuses with the tip or side of an adjacent fold thereby forming pockets or cavities that usually have the shape of a triangle with the base directed toward the extraduodenal part of the common duct Although formed around the entire inner surface of the papilla these pockets are never of the same size or depth Toward the tip of the papilla they become smaller and more shallow and in the final 1 to 2 mm of the papilla the longitudinal folds do not fuse but hang freely their tips often protruding through the papillary orifice

At the base of the papilla the circular intestinal muscle bundles are plainly visible some of these bundles take a curved course as they pass over the papilla When the latter is pulled forward a few narrow flat ribbonlike bands of muscle fibers may be seen that appear to be independent of the intestinal musculature at the base of the papilla If the papilla is turned to one side it can readily be noted that some of these fibers run forward to become attached to the circular muscles of the duodenum The remainder of the fibers run obliquely forward and downward around the side of the papilla to the under surface where their ends either become invisible in the dense connective tissue or *they interdigitate with the opposite end of the same or other fibers* Dardinski states that

> *This group of fibers at the base of the papilla . . . are the only fibers that would*

correspond to Oddi's description of the sphincter muscle of the common duct *

The groove in which the papilla lies is formed by the circular muscles of the duodenum and corresponds to the most constricted part of the duct on the inside. This groove can be seen readily when the circular muscle is removed from the base of the papilla. At the same time one notes the longitudinal muscle of the intestine whose fibers are small and loosely arranged around the common duct.

Some of these fibers are found running forward on the under surface of the papilla and become lost in the dense connective tissue. Others swing laterally away from the normal course and blend with the circular muscles of the intestine *

By separating the fibers of the longitudinal muscle layer and cutting the attachment of a few fibers extending from the base of the papilla to the circular muscle the entire papilla can be removed without difficulty. It may be noted here that Dardinski's Figure 3, which illustrates the arrangement of muscle fibers at the base of the papilla and their connection with the circular muscle, is strikingly similar to one of Schreiber's illustrations.

When the papilla is removed the pancreatic duct comes to view on the ventral side of the common duct along which it proceeds forward. A groove similar to the one formed by the circular muscle around the common duct is also formed around the pancreatic duct just before it comes to lie next to the common duct. Both ducts run through the papilla being enclosed by connective tissue and loosely arranged muscle fibers. White nodules 1 to 2 mm in diameter are scattered over the surface of the papilla in the connective tissue subjacent to the submucosa. These nodules represent racemose mucous glands that empty into the papilla.

Beneath the level of the mucous glands muscle fibers encircle the papilla in an oblique course extending over the sides of the under surface of the papilla where they become lost in the connective tissue or interdigitate with the circular muscle layer. Beneath these fibers and intermingling with them are fibers that course in a longitudinal direction. They extend backward along the surface of the bile and pancreatic ducts and ultimately become lost in the dense connective tissue of the walls of the extraduodenal part of the ducts. When these fibers are traced forward to the tip of the papilla they become invisible in the region where the bases of the longitudinal mucous folds on the inside of the papilla are attached. Many of the obliquely coursing fibers have a similar termination.

Dardinski depicted the blood supply of the papilla as consisting of four main *blood vessels. Two of these are situated on either side of the papilla where the latter penetrates through the intestinal muscle and two are located on either side of the tip of the papilla. White glistening nerve fibers accompany the blood vessels. Traced to the tip of the papilla these nerve fibers become swollen, the swellings probably corresponding to the ganglia described by Oddi in 1891.*

Twenty years before Schreiber, therefore, Dardinski drew the following conclusions from his study of the musculature of the duodenal papilla:

The flow of bile appears to be controlled by the tonicity of the inner circular muscle of the intestine. When by peristalsis or nerve control this tonicity is relaxed the fibers extending from the base of the papilla to the wall of the intestine contract and this contraction probably occurs at the same time that the tone of the inner circular muscle is relaxed *

Contraction of the circular muscle fibers pulls the papilla forward, thereby tending to straighten out the bile duct and

* J Anat 69 169 1935

to open its lumen, allowing the bile to flow into the papilla. Here the bile is held back in the triangular shaped pockets formed by the longitudinal folds about the lumen of the papilla and here bile accumulates until the muscle fibers that surround the papilla contract. When this happens the pockets on the inside are reduced to a minimum, and with a concomitant squeezing of the papilla the bile is expelled in part. The effect on the pancreatic duct is probably the same—i.e., contraction of fibers tends to straighten out the duct, thereby allowing the retained secretion to flow into the papilla from which it is expelled along with the bile. Dardinski concluded that *since the greatest constriction of the common duct is produced by the intestinal muscle, sphincteric action, if there is any at all, should occur at this point of constriction and should be effected by the obliquely running fibers. The muscle fibers present in the longitudinal folds within the papilla actively participate in the process of bile outflow.*

IMPACTION OF THE AMPULLA OF VATER

Opie (1901), pioneer American pathologist, was among the first to state that a small gallstone lodged at the orifice of the ampulla of Vater may divert bile into the pancreatic duct and thus produce hemorrhagic pancreatitis. He came to this conclusion as a result of his experiments at Johns Hopkins University while working with stone impactions in the ampullae of cats. That bile could be forced into the pancreatic duct as a result of the spastic contraction of the sphincter of Oddi at the end of the common duct was first suggested by Archibald of McGill University (1919). He made the suggestion to account for the fact that in 34 of his cases of pancreatitis over 50 per cent did not have gallstones or cholecystitis. Unaware of the work of Oddi in Italy, Archibald on the basis of experiments with dogs as early as 1912 postulated the existence of a common duct sphincter through the resistance of which bile might be forced back into the pancreatic duct and there either cause or help maintain the condition of pancreatitis. In 1913 he stated that instead of doing a cholecystostomy or a cholecystenterostomy in the operation for pancreatitis, it would be more rational to abolish the sphincter action of the papilla of Vater. Deeply interested in the problem and fully convinced that a cholecystectomy would more certainly cure pancreatitis than a cholecystostomy (1918), Judd of the Mayo Clinic (1921) concluded after a study of 170 specimens that in only 4.5 per cent of the cases was the anatomic arrangement of the pancreatic and bile ducts such as to permit conversion of the two ducts into a common passageway by an impacted biliary calculus or by contraction of the sphincter muscle. Mann and Giordano (1923) came to a similar conclusion. In their study of 200 necropsy specimens at the Mayo Clinic they encountered only 40 cases (20 per cent) in which the common bile duct and the pancreatic duct could be converted into a continuous channel. Since the average diameter of the ampulla was 2.5 to 3.5 mm., they concluded that a calculus must be 4 mm. in width before it could cause obstruction.

Rienhoff and Pickrell (1945) likewise substantiated the contention of Judd. In their study of 250 specimens at Johns Hopkins University the average diameter of the ampulla was only 3 mm., hence a calculus must measure 4 mm. to cause obstruction. Furthermore, in only 32 per cent of the cases was an ampulla present and in only 47 specimens (18 per cent) did the length of the ampulla exceed the average diameter of the orifice, allowing complete blockage at the papilla by an impacted calculus. Wangensteen, Leven and Manson of the University of Minnesota Medical School

(1931) in their varied experimental studies on pancreatitis over a period of 5 years observed only 13 instances in which contraction of the gallbladder brought about through its overdistention by air established a common channel with retrogression of bile into the pancreatic ducts and resultant gross hemorrhage

Strikingly different and exceptional is the position taken by Sterling (1949 1953) In studies conducted at the Graduate School of the University of Pennsylvania he emphatically denied the presence of the embryonic ampulla in adult man The apparent enlargement of the termination of the common bile duct is due to an increase in the width of the wall of the duct caused by the presence of the sphincter muscle An actual dilatation of the common bile duct (i e ampulla) does not exist His conclusions are based on 80 dissections studies of transparent specimens and cholangiograms

Sterling maintains that the expanded portion of the common bile duct should be designated as the caruncle or papilla of Vater the length of which varies from 7 to 19 mm (average 14 mm) its diameter varying from 3 2 to 19 2 mm (average 6 8 mm) In 80 dissections he noted that the papilla was elevated above the surrounding mucous membrane in 54 per cent at a level with the surrounding mucosa in 22 per cent and in a depressed position in 24 per cent thus making the papilla visible in 76 per cent The distal part of the common bile duct traveled in a three dimensional long flat S shaped curve and entered the duodenum at a 90° angle In one third of the cases respectively considered its extraduodenal course was extrapancreatic entirely intrapancreatic and partially intrapancreatic Separate orifices for the pancreatic and common bile ducts were observed in 64 per cent (32 of 50 specimens) In the 18 specimens (36 per cent) in which the pancreatic duct joined in a common channel with the common bile duct the average length of the papilla was 14 4 mm that of the common channel 4 4 mm In its transduodenal course the terminal part of the common bile duct as the papilla of Vater is like a funnel its lumen rapidly decreases in size the duct curves through a 3 dimensional route frequently intertwining with the pancreatic duct and in 50 to 60 per cent unites with the pancreatic duct to form an anatomic common channel

In subsequent studies of transparent specimens Sterling noted that the common channel was in the distal third of the papilla in 70 per cent traversed the distal two thirds in 25 per cent and in only 1 case (5 per cent) occupied more than two thirds of the papilla From this Sterling concluded that

a common channel which traverses less than one half to two thirds of the papilla of Vater does not readily permit interductal reflux because of the anatomical disposition of the sphincter masses Thus physiologic common channel exists only in approximately 5 per cent of the cases (Am J Diges Dis 20 124 1952)

More recently Hughes and Kernutt of Australia (1954) maintain that in cases where a common channel for the two ducts exists (two thirds of their 30 specimens) it usually is so short (less than 5 mm) that a stone passing into the papillary portion of the common duct could cause biliary and pancreatic obstruction rather than biliary reflux In cases where the two ducts are completely separated by a thin V shaped papillary septum (one third of their specimens) pressure on the latter by a stone or an inserted tube in the intramural portion of the common duct may obstruct the pancreatic duct Hence in their opinion pancreatic duct obstruction appears more likely to be a factor in pancreatitis than reflux in the duct

Decidedly contrary to these contentions are the following observations After artificially impacting a biliary calculus in the ampulla of Vater of 100 necropsy specimens and after making 66 Wood s metal casts of the ducts of these Cameron and Noble of the University of Minnesota Medical School (1924) concluded that in 66 per cent a conversion of the two ducts into a single communicating system was anatomically possible Howard and Jones of the University of Pennsylvania (1947) confirmed the view of Cameron and Noble for when the papilla of Vater was obstructed by a small calculus or was clamped by a hemostat fluid injected into the common bile duct regurgitated into the duct of Wirsung in 81 (54 per cent) of their 150 fresh specimens

Mehnen a German navy officer (1938) in an examination of 449 adult autopsy specimens found gallstones to be more frequent in cases having a common opening for the pancreatic and bile ducts than in cases where the openings were separate the respective ratio being 5 to 2 *In the 275 cases with possibility* of a reflux of pancreatic juice into the bile passages there were 35 per cent of cases with gallstones while in 174 cases with separate openings only 14 per cent had stones Gallstones were encountered in the bile duct 122 times (27 per cent) occurring more frequently in women (83 times) than in men (39 times) Mehnen claims that different types of stones are correlated with different types of openings In 84 cases having cholesterin pigment–calcium stones there were only 12 cases with separate openings (7 per cent) while 72 cases had a common opening (26 per cent) There were 16 cases of pigment stones these being most frequent in the type II duct opening to wit cases with separate openings in one papilla Cholesterin stones were found in 12 cases of which 10 were specimens having a common opening

Anatomically considered according to Ivy and Gibbs of the University of Illinois (1952) the presence of a small stone at the papillary orifice or spasm of the sphincter of the lower ampulla could cause reflux of bile in the pancreatic ducts and cause temporary obstruction of the pancreatic outflow in from 30 to 70 per cent of the cases the first figure being based on anatomic dissections the second on experiments as recorded in the literature respectively considered

That a common pathway between the common bile duct and the pancreatic duct readily permits the inception of acute pancreatitis is the firm conviction of Doubilet and Mulholland of New York University (1948) as a result of their studies in 21 patients They regard the sphincter of Oddi as a sealing mechanism that raises the pressure in the common system by recurrent spasm The sphincteric spasm can be induced by hydrochloric acid applied to the papilla by emotional disturbances and by pain Furthermore operative cholangiograms performed through a cystic duct tube or *through a T tube in the common duct* demonstrate clearly the existence of an ampulla in which the two ducts drain The sudden distention of the common duct by the contrast medium causes pain and reflex spasm of the sphincter of Oddi Due to a common passageway the contrast medium may be forced up into the pancreatic duct and into the accessory pancreatic duct which can be seen to empty into the duodenum Doubilet and Mulholland call attention to the as yet unsolved problem to wit *how bile can enter the pancreatic duct against the secretory pressure of the pancreas itself*

As stated before a meeting of the American Surgical Association at Quebec (1948) Gage and Ochsner of Louisiana State University are likewise of the opinion that acute pancreatitis usually occurs when the common and pancreatic ducts open conjointly into the ampulla of

Vater and that as a result of obstruction of the common duct by stone or spasm reflux of bile into the pancreatic duct can occur with resultant acute pancreatitis

Cole and Grove of the University of Illinois (1952) call attention to the fact that anomalies of the ampulla of Vater and duodenal papilla may be the cause of persistent symptoms following chole cystectomy They cite two instances in which by section of the sphincter of Oddi they were able to relieve symp toms and pain, to wit in a patient with a stenosis of the sphincter of Oddi and in another having an anomalous junc tion of the common duct with the pan creatic duct by way of an opening no larger than 1 mm in diameter Jones and Smith (1952) recorded the bene ficial results they obtained in patients with chronic relapsing pancreatitis by transduodenal sphincteroplasty They claim that this surgical procedure perma nently interrupted the action of the ampulla of Vater and reduced the effect of the duodenal wall on the intramural portion of the common duct

Literary data on fibrosis of the sphinc ter of Oddi (odditis stenosans Feroldi 1945) and on the precarious results of sphincterotomy have been given recently by Hughes and Kernutt (1954) These Australian surgeons from the Royal Melbourne Hospital state that one of the most controversial features of opera tive cholangiography is the difficulty of interpretation of x ray films Identifica tion of abnormalities at the lower end of the common duct often gives rise to con fusion for the shadow cast by the medium filling the common duct tapers abruptly at the lower end and continues into the duodenum as a slightly tor tuous and narrow pathway The vari able results of operative division of the sphincter of Oddi are due to uncertainty of pathway incomplete sphincter divi sion and probably to postoperative stenosis at the site of sphincterotomy

For further consideration of the sphinc ter of Oddi and the remedial effects obtained through a supraduodenal endo choledochus section of the sphincter the reader is referred to the article of De Muth of Vancouver British Columbia (1942) This Canadian surgeon gave warning of the danger of hemorrhage with resultant contraction when the sphincter ring is unduly stretched or dilated Pertinent here is the physiologic viewpoint as given by J Earl Thomas of Jefferson Medical College (1950) Ac cording to him it is much more prob able that when pancreatitis follows the occlusion of the common orifice the damage is caused by the activation of the pancreatic enzymes in the mixture of the bile and the pancreatic juice in the am pulla as shown by Popper (1948) in his studies on the etiology of acute pan creatitis [11]

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[11] For an excellent comprehensive review of the problem of pancreatitis the reader is referred to the paper by Ivy and Gibbs of the University of Illinois (*Surgery* 31 614 1952) in which 168 references are listed and their contents discussed

The pioneer work of Archibald of McGill Uni versity (1919) on the experimental production of pancreatitis in animals as the result of the resistance of the common duct sphincter is well worth read ing (*Surg Gynec & Obstet* 28 529 1919) It shows that Archibald unaware of the existence of the sphincter of Oddi had postulated its existence to explain his experimental results of obtaining hem orrhagic pancreatitis in cats (1911) through a reflux of bile in the pancreatic duct

The experimental and clinical studies of Wangen steen Leven and Manson of the University of Min nesota (1931) on acute pancreatitis (pancreatic necrosis) constitute a definite landmark in our knowledge regarding causative factors in pancrea titis a total of 289 animals having been used in their experiments over a period of 5 years They noted that with a pressure of from 350 to [illegible] mm of water in the common duct regurgitation of bile in the pancreatic duct was a regular phenomenon and that the lowest intravesicular pressure at which emptying of the gallbladder occurred under the in fluence of overdistention was 60 mm of mercury

The more recent investigative results regarding the secretions of the pancreas have been compiled and critically evaluated by J Earl Thomas of Jef ferson Medical College in a monograph entitled *Secretions of the Pancreas* (Springfield Ill Thomas 1950)

Residual Biliary Stones

Hicken, McAllister and Call, of Salt Lake City (1951), call attention to the fact that from 18 to 20 per cent of patients present aberrations in the anatomic conformation of the extrahepatic biliary system In duct exploration the size of the duct affords a poor index as to its nature for many dilated ducts do not contain stones, while many of the smaller ducts are filled with gravel or bile sand which eludes digital detection Stones incarcerated in a diverticular pocket of the common duct do not necessarily obstruct the duct channel and accordingly both bile and the exploring probe may pass down the duct without indicating the presence of calculi In an examination of 225 patients with a normal biliary system at operation and autopsy they noted that in 22 per cent the common bile duct measured 4 mm or less in diameter in 52 per cent the average was 5 mm while in 26 per cent the ducts were 7 5 to 10 mm or larger Accordingly in 48 per cent of the patients the common duct was larger or smaller than those described in textbooks Since in their experience operative cholangiography afforded an exact method of determining the presence of residual stones the authors concluded that cholangiography is transforming surgery of the biliary tract from a haphazard procedure to an exact science

Garlock of Mt Sinai Hospital New York (1954) is likewise of the opinion that operative cholangiography is a very accurate method of disclosing calculi variously lodged in the duct system The fact that a surgeon may pass a probe or a small sound through the papilla of Vater without meeting obstruction does not exclude the possibility of an overlooked stone He often found calculi situated to one side of the main channel of the common duct in a lateral diverticular projection of the duct those in the lateral projection of the papilla of Vater being very small Garlock maintains that postoperative development of colic chills fever and jaundice quickly establishes the diagnosis of an overlooked stone In their experience manual palpations of the latter can be accomplished by having the surgeon go to the left side of the operating table—i e carrying out inspection from the left side of the patient

The Sphincter of Lutkens

Under the term sphincter collum cysticus Lutkens of the Universities of Freiburg and Berlin (1925) described a sphincteric mechanism at the transition of the neck of the gallbladder into the cystic duct He cites Glisson (1654) Heister (1717) Tobien (1853) and Berg (1917) as having advocated the existence of such a sphincter of smooth muscle In his lengthy monograph on the sphincter Lutkens gives the following reasons for his contention (1) the strikingly different arrangement of the musculature of the body of the gallbladder and of the neck (2) the macroscopic differences and (3) the abundance of muscle in the second and the third valves of the neck Lutkens claims that there is a relative and absolute increase of the circular muscles toward the cystic duct and that the arrangement of the elastic fibers in the collum is essentially different from that in the true gallbladder fundus A tunica fibrosa is seldom seen in the cystic duct and then only in the proximal one half The mass of elastic fibers in the collum is always present in the muscularis the fibers are mainly interfibrillar often being so numerous as to cover the smooth muscle In the muscle bundles of the sphincter of Oddi the elastic fibers are likewise interfibrillar but to a lesser degree than in the collum muscle

The sphincteric aggregate of smooth muscles at the neck of the gallbladder may be ring shaped diffuse arranged in

strands or present as a thickened mass The sphincteric arrangement is best seen when the smooth muscles are ring shaped The greater the aggregation of *smooth muscle at the neck the sooner* is there a cessation of smooth muscles in the proximal part of the cystic duct *Only occasionally can isolated muscle cells be found in the hepatic duct* the wall of which is made up mostly of elastic tissue The mucosa of the gall bladder resorbs that of the hepatic duct secretes In conformity with this the wall of the hepatic duct contains many accessory glands while these are lacking in the wall of the gallbladder Ganglion cells were found to be very sparse in the proximal and the distal parts of the cystic duct but plexiform aggregations of them were encountered in the middle part of the duct Lutkens fully supported the contention of Westphal (to wit that a nervous spasm of the sphincter of Oddi can cause primary obstruction of the biliary passages) and added the sphincter of the neck of the gallbladder as an additional functional unit since, in his opinion it had the structure requisite to acting as a sphincter

The specificity of the sphincter collum cysticus has not been sufficiently established on either an anatomic or a functional basis While Bergman (1927) claimed that Lutkens sphincter is closed during colic Pfuhl (1927) maintains that such a sphincter muscle is not *needed since the valve of Heister* (valvula spiralis 1732) serves the purpose smooth muscle fiber being especially abundant in its first fold The number of folds (valves) in the spiral valve has been computed as varying from 8 to 12 (Hyrtle Cruveilhier Broca) and from 4 to 20 (Soemmering) In his studies of the musculature of the extrahepatic bile ducts Nuboer (1931) likewise found no evidence for the existence of a specific sphincter at the beginning of the cystic duct Puech (1854) described a valve *situated at the confluence point of the* cystic duct with the hepatic duct it being capable of reducing the caliber of the cystic duct to one half or to one quarter of its normal size Repeatedly mentioned in older texts of anatomy its existence is doubted by Testut The nature of the folds (valves) in the cystic duct obviously needs further investigation from both an anatomic and a physiologic point of view

Musculature of the Gallbladder

Diverse and highly controversial have been the concepts proposed in regard to the anatomy and the functional significance of the musculature of the gallbladder Some investigators maintained that it is too meager a mass to effect by contraction an evacuation of the gallbladder this being a passive phenomenon (Auster and Crohn 1922 Haberland 1926 Burget 1927 Gare 1927) or that it is dependent on the motor activity of the duodenal wall (Schreiber 1944) Halpert (1924) and Blond (1927) went so far as to doubt the emptying process of the gallbladder into the duodenum claiming that the bile is resorbed via the cystic vein Winkelstein and Aschner (1925) were unable by either reflex or direct stimulation to elicit a *contraction of the gallbladder sufficiently* adequate to expel its contents Other investigators maintained that the muscle mass is sufficient (½ mm thick in the *contracted condition Aschoff*) and that contraction of the gallbladder is active (Rost 1913 Boyden and co workers 1922 to 1945 Higgins and Mann 1926 Whitaker 1926 Pfuhl 1927 Westphal and Schondube 1927 Wangensteen Leven and Manson 1931 Schreiber 1941) The literature pertaining to the physiologic aspect of this topic is reviewed extensively by Kuntz of St Louis University in his textbook *The Autonomic Nervous System* A typical view denying the contractile power of

the gallbladder musculature is the following

Auster and Crohn of Cornell University (1922) doubted the existence of the sphincter of Oddi as a distinct muscle bundle comparable with that of the sphincter of the pylorus the compressor urethrae and the sphincter ani and maintained that the gallbladder does not enter into the physiology of bile secretion as an active organ In their opinion it certainly does not have an ejaculatory mechanism or the proper musculature for such a function in the same way as one would think of the urinary bladder or the seminal vesicles Instead the outflow of the gallbladder would appear to be in the nature of an overflow incontinence

A denial of the contractile power of the gallbladder musculature is untenable on both an anatomic and a functional basis The most extensive and convincing proof from a physiologic point of view—that the gallbladder expels its contents by force of the contraction of its own musculature—is that given by Boyden In experiments conducted while at Harvard University (1922 1926) he was the first to show (1923) that when cats are fed on a diet of egg yolk and cream the gallbladder immediately exhibits a functional periodicity with marked changes in volume After Sosman Whitaker and Edson of the Peter Bent Brigham Hospital in Boston (1925) had for the first time shown by means of newly introduced cholecystograms the marked effect of fat-containing foods (butter cream olive oil) on the human gallbladder Boyden (1926) assayed the effect of a meal of eggyolk and cream on the gallbladder of cats as visible in x ray films With 79 selected cholecystograms to illustrate his findings he showed that the gallbladder expels its content by force of its own musculature the emptying process being completed 2½ hours after ingestion of the meal while the refilling process began 5 hours thereafter In 1925 Boyden demonstrated the effectiveness of a diet of 4 egg yolks and a pint of cream in the emptying process of the human gallbladder the results noted in 24 young men and women being the same as in the cat—to wit complete evacuation of the gallbladder

For 20 years (1925 to 1945) with the help of many co-workers Boyden investigated the functional activity (especially the evacuation) of the gallbladder in a variety of normal pathologic and experimental conditions (in childhood youth old age and pregnancy in diseased conditions as peptic ulcer cancer pernicious anemia experimentally after chemical or electrical stimulation or after sectioning of various autonomic nerves) and invariably came to the same conclusion viz that the emptying of the gallbladder is accomplished by the contraction of its own musculature One of the most convincing contributions on this point is the work of Boyden and Rigler (1934) in which they showed that faradic stimulation of the stomach and the duodenum in man during fasting induces a narrowing of the gallbladder that may be detected fluoroscopically and by serial cholecystograms

Wangensteen Leven and Manson of the University of Minnesota (1931) in their experimental studies on acute pancreatitis conducted on a large number of animals (289) over a period of 5 years gave definite proof of the contractile power of the gallbladder They showed that if the gallbladder was overdistended with air a retrojection of bile into the pancreas took place The lowest intravesical pressure at which emptying of the gallbladder occurred under the influence of overdistention was 60 mm of mercury At a pressure of from 350 to 570 mm of water in the common bile duct regurgitation into the pancreatic duct was observed regularly That the

evacuating mechanism of the gallbladder is not dependent on the intestinal movements definitely was proved by Higgins of the Mayo Clinic (1927) In experiments with guinea pigs Higgins showed that the egression of bile is dependent on a series of muscular contractions involving in sequence the gallbladder the sphincteric mechanism and the dilated pouch at the distal end of the choledochus

Anatomy of the Gallbladder Musculature Of the newer anatomic concepts the following are the most important Pfuhl of the Anatomical Institute of Greisswald (1927) maintained that it is not permissible to homologize the musculature of the gallbladder with that of the intestine In the gut the tunica muscularis is separated from the mucosa by the submucosa while in the gallbladder the muscularis invades the true mucosa and with the deep layer of the mucosa constitutes the fibromuscularis mucosae (Sudler) The muscularis mucosae is continued into the sphincter of Oddi and into the musculature of the gallbladder the thickness of the latter varies from 150μ to 200μ this amount being sufficient for self contraction Since the musculature of the gallbladder is a muscularis mucosae morphologically different from the tunica muscularis of the gut one should expect its physiologic and pharmacologic reactions to be different as they actually are for like the urinary bladder the gallbladder cannot be emptied by electric stimulation of its wall The musculature of the gallbladder has but one purpose—viz to contract the gallbladder this being possible only with a concomitant relaxation of the sphincter of Oddi the closing power of which is very marked being equivalent to 675 mm of water Since the gallbladder the liver and the bile ducts develop from the same anlage it is evident that the musculature of the bile passages must be homologous to that of the gallbladder For the most part the bile ducts have sparse muscle aggregates and in places are entirely devoid of muscle Even though muscle accompanies the choledochus for a short distance upward only a few split off bundles proceed from the gut musculature to the sphincter of Oddi

Latest Concept of the Anatomy of the Gallbladder Musculature Schreiber of the University of Frankfurt a M (1939 1941) emphasizes the point that since in animals the rump position is horizontal while in man it is erect the topographic relations and the hydrostatic physics of the bile duct system are entirely different in the two groups with resultant necessary differences in required gallbladder musculature the latter being much stronger and more highly developed in animals than in man As a corollary it follows that the results of experiments conducted on the biliary apparatus of animals do not apply necessarily to man

Schreiber investigated the musculature of the gallbladder in a series of mammals and in man paying particular attention to the manner in which the smooth muscle bundles become arranged around the *hollow viscus* where conditions are essentionally different from those when arranged about solid structures Life warm gallbladders were treated with a solution of barium chloride or papaverin and dissected with the aid of a magnifying glass The human material was obtained from 8 executed individuals In man the gallbladder musculature increases from the fundus over the corpus to the infundibulum while in animals the situation is the reverse the strong musculature being at the fundus

The mantle of musculature about the *hollow* gallbladder is arranged in the form of two spiral networks The superficial sheath is orientated transversely and is composed of spirals that run from the right side to the left and from the left

side to the right cross each other and thus surround the entire gallbladder The shortest spirals are at the neck region the largest at the fundus The deep sheath of muscle is a longitudinally spiraled net its longitudinally running fibers being sheared off from the super ficial net The deep longitudinal fibers begin in the infundibulum and in crease toward the fundus where after convergence they rejoin the superficial net on the opposite side Throughout their course they likewise cross each other The superficial net is two to three times as strong as the deep longitudinal net The latter is responsible for the permanent folds of the mucosa From the longitudinal net small muscle bun dles are sheared off into the subepithelial connective tissue where they become anchored to elastic tissue strands The superficial deep and end bundles form a muscular unit which must be regarded as fixed to the gallbladder bed By con traction the gallbladder musculature not only can decrease the diameter of the gallbladder but also can lift up the fundus These activities were verified roentgenographically

GALLSTONES

Incidence of Gallstones and Their Cor relation with Other Diseases A compre hensive report on this topic covering differences in age groups sex and color was made recently by Lieber of the Pathology Department of Jefferson Medical College (1952) An analysis of the statistical data of 26 895 consecutive autopsies performed at Philadelphia General Hospital during a period of 20 years and of 7 771 performed at Jefferson Medical College over a 9 year period (total 34 666) showed that gallstones were found in 3 448 cases or in 9 94 per cent This figure however has little or no significance for gallstones rarely occur before the age of 20 years having been absent in 4 887 autopsies inspected If the latter figure is subtracted then in patients over 20 years of age (29 779) gallstones were present in 11 6 per cent

Lieber gives 10 tables in which he records his statistical analyses as regards the incidence of gallstones in males and females (colored and white) the inci dence of gallstones in age groups (10 to 90 years) in primary carcinoma of the gallbladder in diabetes mellitus in acute pancreatitis and fat necroses in portal cirrhosis in gastric duodenal and peptic ulcers in pernicious anemia in tuber culosis and in various diseases Data on the percentage incidence of gallstones by sex age groups and color as contrasted with their incidence in various diseases are recorded in the table from Lieber (Table 3) on page 96

Significant conclusions drawn by Lieber from his statistical study are the following There is a progressive in crease in the incidence of gallstones from one age decade to the other the inci dence being greater in the white than in the colored race and greater in females than in males Incidence of gallstones was much greater in the white female (21 7 per cent) than in the white male (9 7 per cent) the ratio being 2 2 to 1 Gallstones occur more frequently in the colored female (8 7 per cent) than in the colored male (3 2 per cent) the ratio being 2 7 to 1 In both white males and females however the total incidence of gallstones was greater than in the colored race Significant increases in the inci dence of gallstones occurred in white females between the ages of 50 to 60 and between 60 to 70 in the colored females In males there was roughly a decade dif ference the high points appearing later i e between the ages of 60 to 70 in white males and between 70 and 80 in colored males

As opposed to Robertson of the Mayo Clinic (1945) who after an examina tion of 4 671 autopsies maintained that in both men and women gallstones were

TABLE 3 PER CENT OF GALLSTONES IN VARIOUS DISEASES*

AGE	ALL CASES	CARCINOMA OF GALLBLADDER	DIABETES	ACUTE PANCREATITIS AND/OR FAT NECROSES	PORTAL CIRRHOSIS	PEPTIC ULCERS	PERNICIOUS ANEMIA	TUBERCULOSIS
Female White								
20-30	4.2	0.0	0.0	0.0	0.0	0.0	0.0	3.4
30-40	8.6	0.0	16.6	0.0	16.6	0.0	0.0	3.7
40-50	12.1	50.0	19.0	50.0	19.1	4.1	0.0	5.8
50-60	23.3	50.0	31.3	100.0	30.7	37.0	7.1	17.0
60-70	27.5	68.7	47.2	73.3	38.0	32.5	36.3	18.6
70-80	30.6	69.2	45.0	66.6	41.9	26.3	40.0	23.8
80-90	31.9	100.0	62.5	0.0	57.1	20.0	0.0	27.2
90+	41.4		100.0	0.0		33.3		
Totals	21.7	64.3	38.5	71.4	31.2	23.6	18.6	8.6
Male White								
20-30	0.9	0.0	0.0	0.0	0.0	0.0	0.0	1.7
30-40	2.1	0.0	16.6	0.0	5.7	12.2	0.0	1.5
40-50	4.2	50.0	12.5	50.0	11.1	4.0	0.0	2.7
50-60	7.6	40.0	9.5	33.3	11.5	8.0	0.0	4.9
60-70	12.5	37.5	13.5	44.1	20.6	12.3	0.0	8.7
70-80	16.4	57.1	24.2	0.0	19.0	11.1	28.5	10.4
80-90	21.4	80.0	25.0	0.0	0.0	3.7	0.0	0.0
90+	25.8		20.0			0.0		
Totals	9.7	48.7	17.9	33.3	13.9	9.3	4.4	4.4
Female Colored								
20-30	2.0	0.0	12.5	0.0	0.0	7.7	0.0	1.1
30-40	5.2	0.0	9.3	0.0	0.0	9.1	0.0	2.8
40-50	9.8	0.0	18.7	33.3	8.3	0.0	0.0	4.6
50-60	10.4	0.0	29.4	0.0	23.0	26.1	0.0	15.2
60-70	16.7	40.0	37.7	40.0	0.0	12.5	0.0	35.3
70-80	18.9	50.0	40.2	0.0	33.3	46.1	0.0	55.0
80-90	25.0	0.0	57.0	0.0	0.0	25.0	0.0	75.0
90+	10.0		100.0			0.0		
Totals	8.7	25.0	33.7	22.2	13.2	17.0	0.0	5.3
Male Colored								
20-30	0.3	0.0	0.0	0.0	20.0	0.0	0.0	0.4
30-40	0.9	0.0	0.0	12.5	8.3	3.1	0.0	1.3
40-50	2.1	0.0	5.0	0.0	0.0	0.0	0.0	1.5
50-60	4.2	50.0	8.0	0.0	4.6	3.1	0.0	1.4
60-70	7.7	33.3	15.4	0.0	0.0	0.0	0.0	7.0
70-80	6.6	0.0	33.3	0.0	0.0	0.0	0.0	3.7
80-90	13.6	0.0	100.0	0.0	0.0	0.0	0.0	0.0
90+	9.1							
Totals	3.2	37.5	9.2	4.7	4.3	1.4	0.0	1.1

* From Lieber *Ann. Surg.* 135:403, 1952

found almost exclusively during the active sex life. Lieber concluded to the contrary, to wit, that in both sexes and in both races the incidence of gallstone formation increased with the diminution and the cessation of sex activity.

Carcinoma of the gallbladder definitely is associated with a marked increase in the incidence of gallstones, the increase being threefold in both white and colored females, fivefold in white males and tenfold in colored males. The incidence of carcinoma of the gallbladder in patients having gallstones was 2.5 per cent in white females, 1.6 per cent in white males (ratio of 1.5 to 1), while in the colored race it was 3 per cent in females and 5 per cent in males (ratio of 1 to 1.6). The highest incidence of gallstones in carcinoma of the gallbladder occurred in white females, being 64.3 per cent. In diabetic patients (1,259) beyond 20 years of age, gallstones were present in 30.2 per cent (381 autopsies). An appreciable increase in the incidence of gallstones occurred in each age group, the increase being considerably greater in the colored race. In diabetics over 50 years of age, gallstones were present in approximately 1 of every 2 white females and 1 of every 5 white males, the corresponding ratio for the colored race being 1 of every 3 colored females and 1 of every 7 colored males. Comparable data on sex differences, according to Lieber, have never been recorded in the literature.

In acute pancreatitis (105 autopsies) there was a threefold increase in the incidence of gallstones (77 per cent in white women and 33 per cent in men over the age of 40). In colored females 4 cases of 18 had gallstones, while in colored males only 1 case in 21 (4.7 per cent) was associated with cholelithiasis.

In portal cirrhosis there is a notable increase in the incidence of gallstones, the increase being 13 per cent in white men and women, 52 per cent in colored women and 32 per cent in colored men.

Patients with gastric, duodenal and peptic ulcer showed an increased incidence of gallstones. In 895 patients with peptic ulcer there were 103 cases (11.5 per cent) with gallstones; in 466 patients with gastric ulcer there were 44 cases (9.87 per cent), and in 384 patients with duodenal ulcer stones were present in 52 cases (13.5 per cent). Collectively considered, patients with peptic ulcer showed an increased incidence of gallstones of 8.8 per cent in white females and 95.4 per cent in colored females, but a decreased incidence of 4.1 per cent occurred in white males and a greater decrease of 56.9 per cent in colored males. Lieber refers to the fact that Cross (1929) maintained that there is no association between gastric or duodenal ulcers and cholelithiasis, Cross having based this conclusion on an examination of 405 cases with gallstones among which there were 19 cases (4.69 per cent) of gastric ulcer and 21 cases (5.19 per cent) of duodenal ulcer.

Pernicious anemia showed a decreased incidence of gallstones, for in 120 cases of this disease only 13 (10.8 per cent) presented gallstones. A total decreased incidence of 14.4 per cent occurred in white females and a decrease of 54.6 per cent was noted in white males. No gallstones at all were found in 16 cases of pernicious anemia in the colored race. Lieber accordingly opposed the view of Jones and Joyce (1924) who claimed that in every one of their cases (22) of pernicious anemia a chronic infection of the gallbladder could be demonstrated positively.

Tuberculosis showed a comparable decreased incidence of gallstones, for of 4,807 cases only 214 (4.4 per cent) presented gallstones. An exception is to be made for the colored females who showed a twofold increase of the incidence of gallstones. In the general colored population after the age of 50 years

the incidence of gallstones was 14 0 per cent while in cases of tuberculosis the incidence was 26 6 per cent For each of the topics presented Lieber cites and discusses the pertaining literature

Boyd of the University of Manitoba Canada (1923) after a study of the gall bladder with the binocular dissecting microscope concluded that its function is to absorb cholesterol of the bile and that formation of deposits of cholesterol ester in the mucosa of the gallbladder is an important feature in early cholecystitis Giles of Chicago (1953) discussed the recent changes in the concept that render diseases of the gallbladder and their complications more amenable to surgical treatment According to Sterling and Goldsmith (1953) of the Albert Einstein Medical Center Philadelphia observations of intracholedochal pressure and volume can aid prognosis and management in cases of retained calculi dyskinesia and spasm In cleared specimens they showed (1951) that a stone must be less than 0 3 cm to enter the duodenum

Waugh Johnston and Cain (1954) reported that the incidence of choledocholithiasis in patients undergoing cholecystectomy at the Mayo Clinic ranged from 10 to 16 per cent Of 175 cases in which stones were removed from the common duct 47 (27 per cent) had undergone previous surgical procedure on the biliary tract Pribram (1939) reported that exploration of the common bile duct resulted in overlooked common duct stones in 16 to 25 per cent

Comparative Anatomy of the Biliary Apparatus

In a profusely illustrated article published in the *Journal of the American Medical Association* (13 1273 1929) Mentzer of San Francisco showed that practically all of the anomalies of the gallbladder and the bile ducts in man can be accounted for on a phylogenetic basis Following his studies of the comparative anatomy of the biliary tract and his survey of the literature on biliary anomalies in man, he stated

A knowledge of the normal course of the bile duct in lower animals will aid in anticipating anomalous ducts in man for the latter may represent a reversion to type Almost every recorded anomaly in the biliary apparatus of man has conformed to a normal arrangement in some lower animal

Absence of a gallbladder is a common phenomenon in many mammals (horse elephant, rhinoceros camel deer and many rodents, especially the white rat and the pocket gopher) Mentzer collected 17 specimens of fish 9 species of birds and 26 species of mammals that normally do not have a gallbladder Mann Brimhall and Foster of the Mayo Clinic (1920) made a comparative study of the biliary tract in 15 species of mammals and gave an illustration of each type of gallbladder encountered They found the gallbladder to be wanting in horse deer white rat and pocket gopher It was developed in ox sheep goat dog cat hog monkey and striped gopher and very thin walled in rabbit guinea pig and white mouse The authors found no evidence for a relationship between the capacity of the extrahepatic bile ducts to the presence or the absence of a gallbladder Size of the ducts does not compensate for the absence of a gall bladder

Scammon of the University of Minnesota (1913 1916) by means of wax reconstructions showed that in lamprey (*Petromyzon*) pigeon and rat the gall bladder is developed in the embryo but disappears at a later period In *Petromyzon*, a complete biliary apparatus is formed and persists through the larval stage but, at the time of transformation of the larval to the adult form there is a total degeneration of both gallbladder and duct In pigeon the gallbladder is

developed apparently in a normal way but later is lost completely albeit the duct to which it is attached persists In rat at most there is but a trace of the cystic anlage in very early stages and this soon disappears

Mentzer calls attention to the fact that in many animals the gallbladder lies more or less buried in the substance of the liver (shark many reptiles most marsupials marten stoat weasel ferret masked pig of Japan wart hog common pig and Indian boar) In his studies of the early development of the liver in embryos (3 6 to 9 mm) of dogfish (*Squalus acanthias*) Scammon (1913) found the gallbladder to be embedded in a mass of hepatic tissue known as the cystic lobe It arose as a distinct evagination of the gut and made its connection with the liver duct system secondarily Suspended gallbladders normally are found in salmonoids cyprinoids rays and in many reptiles (Mentzer) In marsupials and phalangista the gallbladder may be found to the left of the ligamentum teres (Macalister)

Pedro Belou Professor of Anatomy at the University of Buenos Aires Argentina (1915) investigated the biliary apparatus of 40 different species in five classes of vertebrates In his large monograph on the biliary passages his phylogenetic study covers 23 pages (pp 221–243) there being a copious illustration of samples from each vertebrate class The following are the most salient items of interest

In fish (Teleostei *Anguilla* Corbina) the liver varies considerably At times voluminous and longitudinal it is in intimate relation with the stomach and the midgut There are from two to eight biliary ducts that unite to form a hepato enteric duct which empties into the initial part of the midgut A gallbladder exists in most species but it is often difficult to distinguish the cystic duct In some species the cystic duct is wanting the gallbladder then drains directly into the hepato enteric duct or into one or two of the biliary ducts The gallbladder may be connected with the liver by one or several cystohepatic ducts

In Amphibia (Urodela salamander Anura frog) the liver (trifoliated) and the pancreas the gallbladder and the cystic duct are always present The hepato enteric duct has immediate relations with the pancreas and empties into the initial part of the midgut a bit to the right of the pylorus

In reptiles (snake lizard turtle) the liver and the pancreas are always present the diverticular apparatus (gallbladder) being constant The hepato enteric duct empties into the intestine at a variable distance from the pylorus The turtle (testudo) has two or three cystic ducts that are anastomosed

In birds (bird pigeon hen goose) the liver is bilobed the right lobe being larger than the left The pancreas lies between the rami of a U shaped duodenum A hepato enteric duct is always present and may drain into the proximal or the terminal part of the duodenum At times there are two hepato enteric ducts—a right which enters the terminal segment and a left which enters the proximal segment of the duodenum

In mammals (guinea pig rabbit cat dog pig ox sheep) the liver is multilobular containing from two to six lobes The hepato enteric duct arises from fusion of one to six ducts and terminates in the first or the second part of the duodenum A tubercle of Vater is nearly always present at the distal duodenal end of the bile duct In some species (horse hare rat) the gallbladder and the cystic duct may be absent as Milne Edwards has shown it to be in elephant rhinoceros tapir and giraffe The cystic duct empties into the hepato enteric duct or into one of the biliary ducts that form it

From his phylogenetic study of the biliary apparatus Belou concludes that

the biliary and the pancreatic systems present a connection that is maintained in all classes although it may be interrupted in some species. This connection is established by the termination of the bile and the pancreatic ducts into a hepato-enteric duct or by a confluent *termination into a common ampulla of* Vater in the wall of the intestine. A diverticular apparatus (gallbladder) may or may not be present. If it is present the vesicle receives bile in three different ways: (a) *through hepatocystic ducts* directly from the liver to the vesicle; (b) through a cystic canal that unites with the hepato-enteric duct at some point of its course—i.e., in the biliary canals or the collective trunk they form; (c) through the medium of a supplementary structure—viz., the ampulla of Vater. *The duct of the vesicle remains* isolated from the hepatic duct and terminates in a common diverticulum. Bile then follows this course: gland, hepato-enteric duct, ampulla of Vater, cystic duct and gallbladder. The tubercle of Vater possesses a system of muscle fibers that may hermetically seal off the bile flow.

Gorham and Ivy of Northwestern *University Medical School (1938)* gave extensive statistical data on the evolutionary contribution of the general function of the gallbladder. In 1936 Schmidt and Ivy noted that animals vary considerably in regard to the quantity of bile produced in the liver, the size and the contractility *of the gallbladder*, the motility of the common duct and the resistance offered by the choledochus to the flow of bile. They concluded that animals without a gallbladder produce a large quantity of bile, while those with a gallbladder that contracted well produce *a small quantity*. Between these there was an intermediate group. They *found that the* amount of bile formed by the liver varied inversely with the efficiency of the contractile apparatus associated with the bile ducts.

After making a phylogenetic study of the problem, Gorham and Ivy found the gallbladder to be a typical vertebrate structure and one that was not lost easily. First found in the larval agnathostomes, *the gallbladder is present in all* insectivores and carnivores (except whales) and it may be lacking among omnivorous or herbivorous forms. Most fishes possess a gallbladder, but it is lacking in true bony fish (Teleostei). All reptiles and amphibia have a gallbladder. In birds the presence of the gallbladder is variable, carnivorous birds usually retaining it. In the primitive mammalian group (Monotremata and Marsupialia) the gallbladder is constant. Carnivorous animals except whales have a gallbladder. Higher mammals with other dietary habits may lose the viscus. Herbivorous forms with continuous feeding habits are most likely to *lose the organ. In short*, the gallbladder usually is retained in forms which most closely resemble the ancestral type and is lost in those forms which vary most widely from the ancestral type. The authors stated that about 300 references on the topic of the phylogeny of *the gallbladder would be placed on record* at the Field Museum of Chicago.

Accessory Gallbladders. A typical double gallbladder with separate cystic ducts normally is found in the burrowing *Orycteropus capensis* (earth hog of Cape of Good Hope). Here the cystic *ducts fuse to form a common cystic* duct before emptying into the hepatic duct, the entire biliary apparatus being enclosed in a common peritoneal coat (Wagner and Owen, *1866*). *The hyrax* of Africa normally has two accessory gallbladders (Owen, *1866*). The otter, the walrus, the seal and the elephant mostly have dilatations in the bile duct at the ampulla of Vater which may function as an accessory gallbladder (Mentzer). The

giraffe is peculiar in that it may or may not have a gallbladder and in some instances has two bladders

The most comprehensive and profusely illustrated investigation on the incidence of accessory gallbladders in animals is that made by Boyden (1926) While at Harvard University he examined approximately 10 000 domestic mammals obtained from the abattoirs of Boston and encountered 156 cases of congenital duplications of the gallbladder The incidence of the latter varied with the species studied as follows 1 in 8 cats (of 2 568 cats) 1 in 28 calves (of 2 555) 1 in 85 lambs and sheep (of 2 560) 1 in 198 pigs (of 2 572) and 1 in 3 000 to 1 000 human beings The gallbladder of cats differed from that of other species in two major respects (a) in the extraordinary number of its anomalies four fifths of which are derived from initial subdivision of the cystic primordium (b) in the peculiar formation of accessory gallbladders from liver-cell cords that normally give rise only to hepatic ducts

The anomalous gallbladders observed in cats were classified into the following types (1) vesica fellea divisa (partially subdivided gallbladders bilobed or trilobed 90 per cent) (2) vesica fellea duplex (2 gallbladders each with its own cystic duct) The accessory vesicle may be an independent outgrowth of the *hepatic duct or of the cystic duct* (7 per cent) (3) vesica fellea multiplex comprising a pseudo multiplex type in which either the normal bladder or the accessory bladder is again subdivided and a true multiplex type consisting of a primary gallbladder and two or more ductular bladders (3 per cent)

In Ungulates (calves sheep pig) Boyden found the anomalies of the gallbladder to be characterized by the fact that there is a suppression of the ductular bladders common in cats and a substitution thereof by a new type of bladder viz the diverticular bladder that originates from the neck of the gallbladder in conjunction with cystohepatic ducts The 91 cases of accessory bladders found in calves were classified into (1) cleft gallbladders (bilobed and trilobed 35 per cent) (2) double bladders that may be of the Y shaped diverticular or trabecular type (52 per cent) (3) multiple bladders pseudo or true (13 per cent) In lambs and sheep accessory lobes of the gallbladder may arise as diverticula of the fundus In pigs having a double gallbladder the smaller lobe probably arises as a diverticulum of the neck

According to Boyden all the aberrant hepatic vesicles encountered in mammals originate early in embryonic life and may be classified into the following four genital groups (1) Cleft gallbladders they originate by initial subdivision of the primary cystic diverticulum of the embryo (chiefly characteristic of cats) (2) Diverticular bladders they are distinct vesicles or subordinate lobes that arise as buds from the neck of the embryonic gallbladder usually being associated with the cystohepatic ducts (3) Ductular bladders these are supernumerary vesicles derived from either the hepatic the cystic or the common bile duct (chiefly characteristic of the human gallbladder but present in cats) (4) Trabecular bladders these are vesicular outgrowths of liver trabeculae bordering *the fossa vesicae felleae* (rare anomalies found as yet only in cattle sheep and probably in cats but undoubtedly related to aberrant cysts found in the adventitial coat of human gallbladder)

Comparative Anatomy of the Biliary Ducts

Variations in the biliary ducts are extremely marked and widespread in the lower animals In honey badger and baboon the cystic duct is very short (Pope) In many fishes birds reptiles

the biliary and the pancreatic systems present a connection that is maintained in all classes although it may be interrupted in some species This connection is established by the termination of the bile and the pancreatic ducts into a hepato enteric duct or by a confluent termination into a common ampulla of Vater in the wall of the intestine A diverticular apparatus (gallbladder) may or may not be present If it is present the vesicle receives bile in three different ways (a) through hepatocystic ducts directly from the liver to the vesicle (b) through a cystic canal that unites with the hepato enteric duct at some point of its course—i e in the biliary canals or the collective trunk they form (c) through the medium of a supplementary structure—viz the ampulla of Vater The duct of the vesicle remains isolated from the hepatic duct and terminates in a common diverticulum Bile then follows this course gland hepato enteric duct ampulla of Vater cystic duct and gallbladder The tubercle of Vater possesses a system of muscle fibers that may hermetically seal off the bile flow

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(agenesis) or of the duct system when a double row of vacuoles appears and persists in the solid cords there is effected a bilocular gallbladder or a septate ductus choledochus

2 Bilaterality in the sense that the pars cystica of the hepatic diverticulum *may be bilobed from the beginning* giving rise to a bilobed gallbladder (vesica divisa) which in man is much rarer than double gallbladder

3 Disproportionate growth of embryonic parts especially of the epithelial gallbladder producing many kinked and bizarre shapes of the gallbladder and effecting the most common (2 to 4 per cent) anomaly known as the folded fundus (Phrygian cap) whereby congenitally the fundus becomes folded like the lappet of a coat within its serosal envelope To this category belongs the double common bile duct explicable on the basis that the original hepatic diverticulum in an aberrant mode of growth becomes divided into two parts one half being left to empty in or near the stomach the other half descending to empty into the duodenum Here likewise belong cases (30 per cent) showing complete involution of the ampulla of Vater

Absence of an ampulla is accounted for by Boyden as follows initially the ampulla is nothing more than a common hepatopancreatic duct extending the entire length of the oblique passage through the intestinal wall the bile and pancreatic ducts joining outside it As development proceeds a connective tissue wedge situated between the two ducts cleaves deeper and deeper until finally in some cases it reaches the tip of the papilla causing the two ducts to open separately

4 Parts that usually disappear may persist thus accounting for a double intestinal orifice Originally the ampulla (hepatopancreatic duct) opens into the duodenum by two orifices (superior and inferior) due to the fact that in the re establishment of the lumen of the duodenum two cavities (right and left) were formed through coalescence of vacuoles Later when the cavities are reduced to one the lower orifice disappears but it may persist (1 per cent)

The *hepatic antrum* is another structure belonging to this category It is a dilatation or a chamber developed at the junction of the common hepatic bile and cystic ducts Large in the pig it is present in all vertebrates Representing a temporary persistence of the body of the main hepatic outgrowth after the chief ducts of the biliary system have become differentiated into slender tubes normally the hepatic antrum participates and usually is used up in the formation of the junctional portions of the three passageways but if its resolution is delayed it may remain as a large chamber at the outlet of the cystic and hepatic ducts and give rise to an idiopathic enlargement of the common bile duct the idiopathic choledochus of Budde (1920)

5 Heterotopic growth which comprises anomalies such as accessory gall bladder pancreatic bladder accessory hepatic and cystohepatic ducts and accessory pancreatic nodules of the gallbladder In mammalian embryos an accessory gallbladder may bud (a) from the cystic duct the hepatic duct or the common bile duct (ductular gallbladder of man) (b) from the neck of the gall bladder in association with cystohepatic ducts (diverticular bladder of cattle and pigs) (c) from the trabeculae which border the fossa of the gallbladder (trabecular gallbladder of cattle sheep and cats) (d) from the portal diverticula of the left ventral pancreas (pancreatic bladder of cats) In man the left part of the ventral pancreas may grow around the left side of the duodenum forming an annular pancreas Liver cords near portal canals may develop into accessory hepatic ducts cords bordering the gall

and herbivorous animals, the cystic duct empties into the common duct far down its course while in birds it may drain into either the right or the left hepatic duct (Mentzer) In cattle according to Boyden the common duct is so short that the duodenum may be said to occupy the porta hepatis and the cystic duct is very long and embedded throughout its length in the liver tissue, to which it is intimately united with minute ducts Hornbill and *Ardea cinerea* (herons) have two cystic ducts that drain from a single gallbladder (Mentzer) (a rare anomaly in man but encountered and removed at operation by Shallow and Wagner of Jefferson Medical College in 1952)

In lower forms the cystic duct may drain directly into the stomach the duodenum or the intestine In the European freshwater fish the bream the cystic duct empties directly into the stomach close to the pylorus (Owen) In many birds and reptiles the cystic duct empties directly into the duodenum Scammon showed that in pigeon which loses its gallbladder in late developmental life two ducts leading from the liver to the intestine are present in the embryo The anterior is called the ductus hepato entericus the posterior consists of two parts the portion between the hepatic trabeculae and the gallbladder being known as the ductus hepato cysticus and the portion between the gallbladder and the intestine being called the ductus cystico entericus

Cystohepatic Ducts These are present in many fishes birds reptiles and mammals By this arrangement of ducts part of the liver bile is directly emptied into the gallbladder or its cystic duct while part of the bile is drained directly into the duodenum by hepatic ducts that do not connect with the gallbladder as typically exemplified in the fish *Lophius* According to Mentzer cystohepatic ducts are best known in turbot and the group comprised of *Siren Lepidosiren* and *Amphiuma* He could not determine their presence in seal, as claimed by Owen but is firmly convinced that they exist in man having encountered them 8 times in 96 necropsies

Accessory hepatic ducts are common phenomena in lower forms for many fishes birds reptiles and mammals normally have one or more hepatic ducts that drain directly from the liver into the intestine Samples according to Mentzer are flounder swordfish *Xiphias*, iguana alligator curassow duckbill Chelonia and echidna Many of the lower animals possess no choledochus or the cystic duct joins the hepatic duct In horse the latter enters no common bile duct exists In animals without a common bile duct part of the bile is drained through cystohepatic ducts part of it by hepatic ducts emptying directly into the intestine According to Mann Brimhall and Foster (1920) there is a decided variation as to the distance between the pylorus and the point of entry of the hepatic duct In horse the latter enters into the duodenum between 10 to 20 cm from the pylorus while in ox the distance is from 50 to 70 cm Ducts enter the duodenum from 0 5 to 1 5 cm from the pylorus in rabbit and from 0 4 to 0 8 cm in guinea pig from 1 5 to 2 5 cm in rat and from 4 to 5 cm in pocket gopher These measurements show that the entry of the bile duct into the duodenum is relatively closer to the pylorus in species without a gallbladder than in those possessing one

Developmental Anomalies of the Biliary Tract

Boyden of the University of Minnesota (1944) summarizes the developmental anomalies of the biliary tract as follows

1 Faulty resolution of the solid epithelial stage of the biliary tracts causing a congenital absence of the gallbladder

duct at operation The high number of contributions is justifiable for there is a roentgen anatomy of the biliary apparatus as emphasized and extensively shown by Norman (1951) of the University of Lund in his copiously illustrated monograph on cholangiography

Hicken and Crellin (1940) were the first to employ cholangiography in infants and it subsequently has been used in infants by Dahl and Crellin (1952) Swenson and Fischer (1952) Moysen Collet and Richard (1953) and Ericsson and Rudhe (1951) the latter giving the most extensive roentgen anatomy of the biliary tree in infants and children

Pioneer reports on the segmental distribution and the mode of branching of the intrahepatic bile ducts as ascertained by cholangiography corrosion casts or other means are those of Hjortsjo (1948) and Norman (1948) of Sweden Tainsinger of South Africa (1950) Elias and Petty (1952) and Healey and Schroy (1953) of the United States and Schmidt and Guttman of Germany (1954) Nettelblad of the Anatomical Institute of the University of Lund Sweden (1954) recently published an excellent monograph on a comparative study of the lobulation and the inner topography of the mammalian liver (*Acta Anatomica* **21** 1–251 Suppl 20 1954) His investigative work conducted under his chief Hjortsjo comprised a study of the embryologic development of the liver of the hamster

Roentgenologic delineation of the abdominal aorta and its branches following direct translumbar injection of a radiopaque medium was first introduced by Dos Santos Lamas and Caldas (1929) and subsequently was adopted and modified by Saito and Kamikawa (1932) Osario (1933) Doss Thomas and Bond (1942) Nelson (1942 1945) Shallow Herbut and Wagner (1946) Wagner (1946) Price and Wagner (1947) Wagner Price and Swenson (1947) Wagner and Price (1950) and others

Fatality following abdominal arteriography is reported to be extremely rare No accident was noted by Dos Santos in 300 subjects by Osario in 100 and by Nelson in over 100 cases Wagner Price and Swenson had one accident in 50 subjects upon whom abdominal arteriography was performed at Jefferson Medical College These authors maintain that the method

should be employed as a diagnostic adjunct by carefully trained personnel only after simpler and standard studies have failed to yield sufficient information to reach a necessary conclusion (*Am J Roent & Rad Ther* 58 591 1947)

From a historical point of view it should be noted that the anatomist Brause of Germany (1896) was the first to use roentgenograms in the study of blood vessels injected with some opaque material (metallic mercury) he having employed it for the blood vessels of the human hand

Absence of Gallbladder As emphasized by Schachner of Louisville Kentucky (1916) congenital absence or agenesis of the gallbladder must be distinguished from an absence of the gallbladder due to destruction of same by some inflammatory process As reported in the literature absence of the gallbladder is twice as common in females as in males With agenesis of the viscus the bile ducts are usually normal However Bower of the Samaritan Hospital Philadelphia (1928) reported a case of congenital absence of gallbladder cystic duct and common duct the hepatic ducts being very small He gave 67 short abstracts of reported cases of agenesis Mentzer and Nagel (1926) found 1 case of agenesis in 1 600 necropsies Mentzer having calculated 50 from the literature Gross (1936) and Mellvile (1937) found 38 reported cases and Dixon and Lichtman (1945) calculated 90 cases includ

bladder fossa may become vasa aberrantia (epithelial lined cysts) sometimes found in the adventitia of the human gallbladder the neck of the gallbladder may give rise to cords which differentiate into cystohepatic ducts Finally multiple outgrowths of pancreatic tissue may appear in the wall of the human gallbladder in the form of an aggregate nodule simulating in external appearance an appended lymph node

ANOMALIES OF THE GALLBLADDER AND THE BILIARY DUCTS IN MAN

As shown by Mentzer of San Francisco (1929) most of the anomalous biliary structures in man represent normal arrangements in the lower animals To be familiar with these is a great asset not only to the surgeon but also to the roentgenologist for as stated by Ericsson and Rudhe of Stockholm (1954) the successful evaluation of cholangiography findings cannot be done without a complete knowledge of the gross anatomy of the biliary system An excellent comparative study of the biliary ducts from fish to man is given by Belou of Buenos Aires Argentina (1915)

Extensive reviews on anomalies of the entire biliary apparatus are those of Thomson (1892) Schachner (1916) Boyden (1926) Bower (1928) Ladd (1928) Mentzer (1929) Gross (1936 1953) Stolkind (1939) Dixon and Lichtman (1945) and Corcoran and Wallace (1954) Extensive reviews on the normal variational anatomy of the bile ducts have been compiled by Belou (1915) Eisendrath (1918 1920) Flint (1923) Thompson (1933) Moosman and Coller (1951) and Johnston and Anson (1952) Reports and reviews on the congenital malformations and obliteration (atresia) of the extrahepatic bile ducts are those of Howard and Wolbach (1911) Holmes (1916) Harris (1926) Bower (1928) Ladd (1928 1935) Levine (1928) Sweet (1932) Cesarini (1935) Gross (1936 1953) Donovan (1937) Hicken and Crellin (1940) Dahl Iverson and Gormsen (1943) Gray DuShane and Heneger (1948) Rosemond Burnett and Beecher (1949) Ahrens Harris and MacMahon (1951) Hsia Patterson, Allen Diamond and Gellis (1952) Moyson Gillet and Richard (1953) Corcoran and Wallace (1954) and many others

Reports on congenital cystic dilatation of the common duct are those of Budde (1920) Boyden (1926) Judd and Greene (1928) Zinniger and Cash (1932) Gross (1933) Swartley and Weeder (1935) Wright (1935) Blocker H Williams and J Williams (1937) McWhorter (1939) Smith (1942) Shallow Eger and Wagner (1946) Davis (1948) Keeley (1948) H Archambault R Archambault and Lasker (1950) and others

Reports on the utilization of cholangiography first introduced by Reich of Germany (1918) and Graham and Cole of America (1924) as a means of exploring anatomic variations of the gallbladder and the extrahepatic bile ducts are those of Millikan and Whitaker (1925) Boyden (1926) Nichols (1926) Barsony and von Friedrich (1928) Levine (1928) Chiman (1929) Cotte (1929) Gabriel (1930) Overholt (1931) Mirrizzi (1932) Vastine (1934) Hicken (1934 1947) Meyer Carter and Meeker (1937) Pribram (1939) Doubilet and Mulholland (1948) Golden (1948) Hughes Hannan and Mulvery (1948) Hicken Corry and Franz (1949) Priestly Walters Gray and Waugh (1949) Sterling Friedman Ravel and Solis Cohen (1949) Norman (1951) Swenson and Fischer (1952) Vadheim and Rigos (1952) Best Rasmussen and Carlyle (1953) Corcoran and Wallace (1954) Howard (1954) Hughes and Kernutt (1954) and many others By 1949 according to Hicken 289 articles had appeared on the subject of operative cholangiography many dealing with residual stones missed in the common

development (second month) The gallbladder need not be imbedded entirely in the liver A small part of the neck may be visible The fundus may protrude from the superior surface of the liver (Lemon 1905 Stetten 1933) The entire viscus may be discernible except for a bridge of hepatic tissue that passes from the quadrate lobe to the right lobe completely encircling a portion of the body (Walton 1912 Corcoran and Wallace 1951) McNamee of St Alexis Hospital Cleveland (1935) maintains in his report of 2 cases that it is impossible to make a preoperative diagnosis of an intrahepatic gallbladder except by roentgen examination and cholecystography In 1951 this was accomplished successfully by Ericsson and Rudhe of Stockholm Sweden who demonstrated two cases of a partially intrahepatic gallbladder in infants and recommended this procedure in biliary obstruction claiming that the risk of laparotomy and cholecystography of the normal biliary tract is negligible

McNamee calls attention to the fact that extreme fibrosis and atrophy may follow inflammation reducing the gallbladder to the size of a pea (Walton) thus giving rise to an apparent agenesis of the gallbladder In his opinion the functional activity of the intrahepatic gallbladder probably is impaired Since it cannot empty completely its contents become thickened and a nidus is formed setting the conditions for stone formation Favoring this view is the fact that 60 per cent of the reported cases of intrahepatic gallbladders had gallstones

Cases of an intrahepatic gallbladder have been reported by Hochstetter (1886) Devé (1903) Rolleston (1904) Lemon (1905) and more recently by Wieder of the University of Pennsylvania (1915) Walter and Neiman of Chicago (1931) De Witt Stetten of Lenox Hospital New York (1932) McNamee of St Alexis Hospital Cleveland (1935) Corcoran and Wallace of Suffolk and Norfolk Virginia (1951) and Walton of the London Hospital (1912) Devé of the School of Medicine of Rouen France found partially imbedded gallbladders in 11 of 133 children and in 8 of these the fundus alone was imbedded In adults the same condition was observed by O Day (1905) Kehr (1913 4 cases) Schachner (1916) and Mentzer (1921) Lemon of Australia encountered a case at operation which to his great surprise contained two stones The first case reported in America was that of Walter and Neiman of Chicago (1931) encountered in a woman 27 years of age The distance between the liver and the gallbladder (which contained stones) measured from 3 to 4 cm No cystic duct was seen outside of the liver The cited authors collected 16 cases from the literature

De Witt Stetten s paper presented before a meeting of the New York Surgical Society April 27 1932 contains one of the best illustrations of an intrahepatic gallbladder It was found in a man 45 years of age contained a gallstone and was removed with fatal issue Stetten admitting that it should only have been opened His illustration of the case (Fig 14) should be given detailed study for the liver depicted strikingly verifies in external morphologic markings the segmentation of the liver as recently ascertained by Hjortsjo (1948) and Healey and Schroy (1953) in corrosion casts In his description of the liver Stetten stated that

> the lateral portion of the right lobe is almost completely divided by means of a deep lateral fissure into a smaller outer and a larger inner portion At the point that corresponds to the normal bed of the gallbladder there is another deep fissure between two portions of the median part of the right lobe which were adherent to each other Following this fissure backward a

ing 10 cases observed at the Mayo Clinic Other cases were reported by Barnstorf (1931) Tallmadge (1938) Robertson Robertson and Bower (1940) Latimer Mendez and Hage (1947) Villareal (1948) Nelson Hatch and Jackson (1949) Kobacker (1950), Policy and Sachs (1954)

Ericsson and Rudhe of the Karolinska sjukhuset Stockholm Sweden (1954) in their pioneer and extended study of cholangiography in infancy as an aid to operative diagnosis of biliary obstruction found 2 cases of absence of the gall bladder and extrahepatic ducts

According to Gross (1954) more than 400 cases of atresia of the bile ducts have been reported in the literature and of these about one sixth had an absence of the gallbladder the condition not being accompanied by a compensatory enlargement of the biliary ducts Some of the earliest cases of agenesis of the gall bladder reported are that of Arthur Latham (1898) as recorded in the *Proceedings* of the Anatomical Society of Great Britain and Ireland (1899) and that of Huber reported in the *Philosophical Transactions* London (1944) One of the more recent to be reported is that of Mackmull of Jefferson Medical College

Gulden Mackmull s case of a congenital absence of the gallbladder was the first and only one observed at the Daniel Baugh Institute of Anatomy in over 3 000 dissections (ita Schaeffer) Mackmull verified the absence of the gall bladder with an x ray film of the biliary system previously injected with lipiodol Absence of an accumulation of an opaque mass inside the liver proved conclusively that the gallbladder was absent i e was not embedded in the liver substance The distribution of the intrahepatic bile ducts as traced with India ink after lipiodol injections is well illustrated and compares favorably with the arrangement of ducts noted by Healey and Schroy (1953) in their vinyl acetate corrosion casts of the biliary tree

Rudimentary gallbladders about the size of a goose quill were described very early by Cursham (1840) Wilks (1862) and Roth (1868) The one that Levine of Brooklyn (1928) detected by means of a cholecystogram was about one third of the normal size and was conical Howard and Wolbach of Iowa City (1911) in a paper published from the Montreal General Hospital, reported a case of a male 6 weeks of age in which the gallbladder was very small and presented a bulbous enlargement of the cystic duct 1 cm long and 0 05 cm broad The bladder could be filled with water but no flow came through the cystic duct The hepatic cystic and common ducts consisted of fibrous cords in which no lumen could be found Despite the absence of the gallbladder the bile ducts as reported in the literature are usually normal The fossa for the gall bladder may remain 7 cases having been reported (Dixon and Lichtman 1945)

Two theories have been proposed to account for the agenesis of the gall bladder (1) failure of the gallbladder to develop from the hepatic diverticulum resulting likewise in the absence of the cystic duct (2) failure of the gall bladder bud to resolve itself from the solid embryonic stage the presence of a solid cord residue favoring this view (Theodor 1909) Congenital absence of the gallbladder according to Dixon and Lichtman is a distinct disadvantage for of the authentic 60 cases studied in the literature 48 had jaundice Stones were present in 27 per cent, pancreatitis in 18 per cent and hepatitis in 8 per cent

Intrahepatic Gallbladder Absence of the gallbladder on the exterior surface of the liver does not necessarily mean that the gallbladder is wanting for it may be imbedded in part or wholly in the substance of the liver as it usually is during a period of its ontogenetic

(1951) reported two cases as seen by cholangiograms In a review of the literature Verstanding and Moore (1948) found that a double gallbladder had been diagnosed preoperatively by cholangiography in 12 cases which with their own case made a total of only 13 instances for most of the reported double gallbladders were found after the abdomen was opened

Interesting is the case of the double gallbladder reported by Croudache of Grey s Hospital Pietermaritzburg Natal (1951) While removing the gallbladder in a woman of 52 years of age Croudache noted that it was peeling off from what was first taken for a diverticulum of itself situated between it and the liver However he was able to separate the gallbladder from the other structure which was then revealed as a gallbladder lying above the first Its duct penetrated deeply into the liver substance The second gallbladder was about one half the size of the other and contained 29 small stones As early as 1911 Sherren of the London Hospital removed at operation two complete gallbladders in a woman 25 years of age The bladders one larger than the other were joined only along a narrow portion of their circumference Each of the two complete cavities possessed its own cystic duct that of the larger vesicle entered the common duct The specimen was presented to the Museum of the Royal College of Physicians (No 56 131)

As summarized by Cross (1953) the types of double gallbladders recorded in the literature comprise the following types (1) 2 with a Y shaped cystic duct (2) 2 with a separate cystic duct (3) 2 with one cystic duct entering the liver (4) 2 with one partially embedded in the liver and its cystic duct entering the hepatic duct (5) 2 one normally situated the other being on the under surface of the left lobe and communicating with the left hepatic duct (6) 2 one being in the gastrohepatic ligament its duct emptying into the common bile duct

Corcoran and Wallace of Virginia (1951) offer the following commonly accepted embryologic explanation for the formation of a double gallbladder An accessory gallbladder directly connected with the cystic duct the common duct or the hepatic duct arises from one of the small cellular outpocketings (rudimentary duct buds) occurring on the bile ducts in the embryo being most numerous at the junction point of the two hepatic ducts with the common duct Normally these buds regress and disappear but the persistence and the growth of one of them may lead to the formation of an accessory gallbladder If the bud from which the supernumerary gallbladder originates is on one of the hepatic ducts or the common duct then the accessory gallbladder will have a complete cystic duct of its own If however the primordium originates from the cystic duct then the accessory and the normal gallbladder will be connected with the common duct by a Y shaped cystic duct

As stated by Boyden complete duplication of the human gallbladder is extremely rare In over 5 000 adult bodies dissected at the Daniel Baugh Institute of Anatomy of Jefferson Medical College since 1914 under the directorship of Schaeffer (1914–48) and Bennett (1948–) no double gallbladder was ever encountered in an adult However in 1952 the author found a double gallbladder in a male infant under dissection (Fig 152) The two gallbladders are completely separated and lie side by side covered by a common serosa From each vesicle a cystic duct emerges but until by detailed dissection the author can ascertain whether the *cystic ducts* join to form a Y shaped common cystic duct or join the common duct separately commitment cannot be made as

very much thickened gallbladder could be felt completely surrounded by liver tissue (*Ann Surg* 97 296 1933)

The left lobe was also somewhat lobulated

Double Gallbladder These may have a separate or common serosal covering They may be partially connected with one another by connective tissue they may be contiguous or they may be situated with a variable interval between them Finally they may be of equal or unequal size the supernumerary gallbladder usually being *smaller*

Partial or complete duplication of the human gallbladder according to Boyden (1926) *is extremely rare From requested* reports received from anatomic laboratories and clinics Boyden calculated *that out of a total of* 9 221 *bodies and* 9 970 hospital patients only 5 authentic cases were observed A review of the literature revealed *only* 17 cases of double gallbladder These Boyden classified into two types (1) Y shaped type *in which the two cystic ducts unite* before emptying into the common bile duct the two bladders usually adhering *to each other (2) completely separate* vesicles that empty separately into the common bile duct Boyden was able to find *only one* complete picture of a double gallbladder and a double cystic duct—viz the case of Blasius (1678) in *which the accessory gallbladder was* smaller Since the latter s duct entered the choledochus just above the entrance of *the pancreatic duct* Boyden suggested that the accessory vesicle might have been a pancreatic bladder comparable with that existent *in the cat*

Gross (1936) in his report of a double gallbladder made a very extensive review *of the anomalies of the biliary* apparatus and stated that in the literature he found 28 recorded instances of a doubling of this *viscus and gave a small* sketch of each case Cruveilhier (1860) found a double gallbladder from the fundus to the neck There were two *cystic ducts one communicated with the* hepatic duct and the ending of the other (which subdivided) could not be determined since it had been cut *It was* obviously a case of a double gallbladder with a single neck and two cystic ducts Schachner (1926) found a double gallbladder with independent necks and two cystic ducts Both bladders contained stones and were drained Kehr (1903) encountered a case at operation as did Braun (1925) Haberland (1926) found 9 reported cases Wischnewsky (1925) *found two* gallbladders at operation one on the right the other on the left side of the falciform ligament A comparable observation *was made* by Purser (1886) who found one gallbladder suspended from the right lobe the other from the *left lobe in a woman* 31 years of age (*Brit Med J* 1886) Corcoran and Wallace of Virginia (1954) observed four *cases of a double gallbladder* two of which were verified at operation In one case a cholecystogram showed two shadows *(with stones) one being* larger than the other In the other case a cholecystogram even after a double dose of *dye did not* visualize the gallbladder By means of a roentgenogram Nichols of the Cleveland Clinic (1926) previously had diagnosed a double gallbladder in a physician 51 years of age the condition showing up as two distinct rows of stones

Claman of Hartford Connecticut (1929) was the first to visualize preoperatively a double gallbladder by means of a cholecystogram without the help of recognition of *two rows* of stones The second vesicle lay behind and below the first shadow Since 10 minutes *after the ingestion* of a fatty meal both shadows were reduced in size a negative report was made *Hayes* (1931) had noted one with dye in the two separate bladders while Cave

bladders as distinct vesicles or subordinate lobes that arise as buds from the neck (at times from the fundus and the body) of the definitive gallbladder Chiefly characteristic of cattle (Ungulates) they may or may not be associated with cystohepatic ducts that in the embryo pass from the gallbladder bud or the upper part of the cystic duct to the liver substance If the cystohepatic duct drops out the diverticulum remains appended only to the gallbladder

The first description of the diverticular type of gallbladder in man was made by von Heister in 1717 and as early as 1890 Courvoisier found 28 cases reported in the literature of which 18 had stones Gallbladders with diverticulum were noted by Straub (1896) and by Sebening and Schondube (1925) the latter having observed a case in which the diverticulum was of such large size as to interfere with the emptying of the stomach

The diverticulum (i e the rounded saccular area that appears to be tied off from the rest of the gallbladder) may occur anywhere along the surface of the gallbladder from the fundus to the neck Gross (1936) observed 10 instances the diameter varying from 0 5 to 1 5 in in diameter He regarded them to be of congenital origin

The roentgenographic appearance of the diverticulum has been described by Barsony and von Friedrich (1928) Vastine (1934) and Corcoran and Wallace (1954) Vastine pointed out that a calculus in the diverticular pouch can be detected by its separation from the gallbladder shadow and its constant relation to it Corcoran and Wallace figured a case showing a diverticulum of the fundus and a large nonopaque stone in the gallbladder In their opinion the diverticulum of the fundus may be due to an incomplete resolution of the solid stage through which the gallbladder passes in the embryo an account of which is given by Scammon

Phrygian Cap Gallbladder In this congenital anomaly the top or fundus is sharply kinked the bent piece being turned over like a lappet of a coat The odd form was described first by the German pathologist Bartel in the *Frankfurter Zeitschrift fur Pathologie* (1916) His first report was on three autopsy specimens Two years later he reported on 10 more cases from infancy to old age obtained at autopsy and concluded that the deformity was definitely of congenital origin and associated with constitutional inferiority as lymphaticism tuberculosis hernia etc Bartel used the term Phrygische Mütte (cap) because the folded fundus has a striking resemblance to the headgear worn by the people of Phrygia Asia (Incidentally the Goddess of Liberty is still portrayed occasionally wearing this type of head dress)

The most extensive investigations on this anomaly of the gallbladder were made by Boyden (1935) and by Meyer Carter and Meeker (1937) Barsony (1927) Levine (1928) Cesarina (1935) Gross (1936) and Corcoran and Wallace (1954) discuss the anomaly as one of the many met with Barsony regarding it as a pseudodiverticulum of the gallbladder

On the basis of embryonic studies (7½ month fetus) Boyden (1935) distinguished two types of the Phrygian cap anomaly (1) the concealed or retroserosal caused by aberrant folding of the epithelial anlage of the gallbladder within the embryonic fossa of the gallbladder (2) the serosal caused by the aberrant folding of the fossa itself in the embryonic stages of development In a series of 200 cholecystograms Boyden noted that 18 per cent exhibited a marked kinking of the gallbladder either between the body and the infundibulum (24 cases) or between the body and the fundus (6 cases) (*Am J Roentgenol* 35 589)

to the exact ultimate mode of drainage of the two cystic ducts

Bilobed Gallbladder According to Boyden (1926) who studied thousands of cases in mammals bilobed gallbladders occur frequently in the animal kingdom especially in cat but are extremely rare in man and must not be confused with the hourglass gallbladder which is definitely not a variety of the bilobed type but a morhpologic deformation As anatomically defined a bilobed gallbladder is a bifid structure and includes cases in which the two gallbladder cavities are drained by a common cystic duct Cross (1954) and Corcoran and Wallace (1954) distinguish two types (1) the gallbladder which has a longitudinal split made by an internal septum that divides the cavity into two chambers which communicate at the proximal end and have one duct (2) a form in which there is a complete division of the fundic portion into two separate lobes often of unequal size The two portions fuse at the neck of the gallbladder forming a common cavity drained by a common duct

Bilobed gallbladders have been reported by Cruveilhier (1865) Deaver and Ashhurst (1914) Schachner (1916) Kaufman (1922) Rycroft (1923) Meyer (1926) Ullman (1926) Philipps Isaacs and MacDonald (1931) and Corcoran and Wallace (1954) Boyden (1926) *saw the x ray film of Ullman s case and* regarded it as a true deeply cleft bilobed gallbladder He found the bilobed condition of the gallbladder in man to be much more rare than the duplex (double) gallbladder Developmentally considered in his opinion the duplex gallbladder in man does not arise as a primary subdivision of the embryonic hepatic primordium into two parts but represents a growth of a secondary vesicle from some other part of the biliary tract subsequent to the formation of the definitive gallbladder Gross (1936) maintains that the bilobed gallbladder in which the two cavities are separated only by a longitudinal septum most probably represent an incomplete resolution of the solid *stage through which* the gallbladder usually passes in development Instead of the latter s cavity being re established a portion of the solid structure remains to become a fold or septum

Hourglass Gallbladder This type is one in which at about the middle and the lower thirds of the bladder a circular *constriction divides it into* a wider upper and a narrower lower part One or the other of these divisions may have stones Levine of Brooklyn (1928) and Corcoran and Wallace of Virginia (1954) figured cholecystograms in which the hourglass deformity of the gallbladder is very clearly outlined

Hourglass gallbladders were reported by Courvoisier (1890) Hartmann (1891) Malcolm (1907) Morton (1908) and Toida (1913) In Morton s case stones were present in the upper and the lower parts In the 15 cases reported by Courvoisier examination revealed stones or traces of their previous presence Hartmann and Malcolm explained the hourglass gallbladder in their cases as due to a cicatricial contraction secondary to inflammation Boyden (1926) maintained that the hourglass gallbladder may simulate and be mistaken for a vesica fellea divisa but upon in*flation and dissection* can be proved to be definitely not bilobed Corcoran and Wallace (1954) were undecided as to whether the bilobed condition was due to congenital malformation or to aberrant functional *morphology The fact* that they appear in children with no signs of inflammation favors the view that they are of congenital origin (Gross 1936) Levine (1928) regards the congenital viewpoint as the most plausible one

Diverticulum of the Gallbladder Boyden (1926) defines diverticu all

the left lobe of the liver i e to the left of the falciform ligament As emphasized by Walton of the London Hospital (1912) who encountered a case well to the left of the umbilical vein a left sided gallbladder should not be confused with a gallbladder displaced to the left owing to atrophy of the left lobe as described and illustrated by Rolleston (1901) Walton found 3 cases reported in the literature viz that of Hochstetter (1886) Deve (1903) and Lemon (1905) Schachner (1916) collected 8 reports in the literature Kehr of Germany (1902) had a case of a left sided gallbladder it being an independent development of a secondary gallbladder bud directly from the left hepatic duct as he explained it In left sided gallbladders the cystic duct may enter into the right hepatic duct or into the junction point of the hepatic and cystic ducts

Harris of the Washington University Medical School St Louis Missouri (1926) described a case of an ectopic gallbladder in which the cystic duct passed to the right and then made a hairpin bend whereby the gallbladder became displaced from the normal fossa and occupied a horizontal position behind the falciform ligament with its fundus 2 cm to the left of the midline

Retrodisplacement of the Gallbladder In some instances the gallbladder has a retrodisplacement i e it courses upward and backward ultimately reaching the inferior and the posterior surfaces of the liver It may pass downward and backward to become lodged to the right of the vertebral column (Baldwin) It may extend along the vena cava inferior in an upward and backward direction without being visible or it may be placed on the posterior edge of the inferior surface of the liver behind the peritoneum being palpable but not visible (Ferguson 1904) Such displaced gallbladders according to Corcoran and Wallace (1934) are difficult to remove surgically and are due to a migration of the gallbladder bud from its normal position to its final fixation As a result of the malrotation of the gallbladder bud the gallbladder may lie in a horizontal position behind the falciform ligament the case reported by Harris of St Louis (1926) being an example of this type of ectopic displacement To this category also belong the case reported by Gay (1902) where the viscus was completely surrounded by liver tissue and that of Deaver and Ashhurst (1914)

A case in which the round and falciform ligaments were transposed to the right of a normally situated gallbladder was observed by the author once in 500 bodies (Fig 80) Another oddity noted by the author was a gallbladder located cryptically behind the duodenum and the transverse colon so much so that upon opening the abdomen no trace of the gallbladder could be seen (Fig 41)

Situs Viscerum Inversus With a transposition or mirror image of the abdominal organs the gallbladder lies on the left side of the body as does the liver Verano of Philadelphia (1942) while holding a Ross V Patterson fellowship in anatomy at Jefferson observed a case of a complete situs inversus in an adult colored male it being the only case encountered in 3 000 dissections in the Daniel Baugh Institute over a period of 40 years Details regarding its blood supply as worked out by the author are given in Figure 94 of this atlas no comparable illustration having ever been reported in the literature Horn of Wichita Kansas (1915) operated on and drained such a transposed gallbladder with recovery William and Charles Mayo encountered but one case in all their experiences Bland Sutton (1907) observed one case in 3 000 abdominal sections and Kehr (1905) noted two cases in 10 000 autopsies

Levine of Brooklyn (1928) depicted a Phrygian cap gallbladder encountered in a woman 26 years of age the capped gallbladder being produced by a notch between the body and the ampulla He believed it to be a part of a constitutional disease being associated with hyperthyroidism menstrual irregularities and sterility

Meyer Carter and Meeker of the New York Postgraduate Medical School and Hospital of Columbia University (1937) illustrate 8 developmental stages in the formation of the Phrygian cap gallbladder In 100 specimens they found 6 instances of a deformity of the fundus and in a review of 1 000 routine cases of cholecystograms noted that about 4 per cent of the cases showed septal divisions corresponding to the Phrygian cap deformity The septum may cut one fourth of the diameter of the fundus or one half or four fifths or it may cut across the entire diameter separating the fundus from the body and leaving only a small opening connecting the two compartments No signs of gallbladder disease or bile stasis were noted

In their studies of congenital anomalies of the gallbladder Corcoran and Wallace of Virginia (1954) regarded the Phrygian cap type as one that is often overlooked despite the frequency of its occurrence (Boyden 3 6 per cent Meyer Carter and Meeker 4 per cent) In Figure 7 these authors give a clear cut illustration of a Phrygian cap gallbladder as seen in a cholecystogram and remark that *the cap may simulate a stone in the gallbladder* As instanced in one of their cases a septum may divide the gallbladder into two distinct compartments communication between the two being restricted to a small aperture 0 5 cm in diameter In accord with Boyden (1935) and Meyer Carter and Meeker (1937) they regard the Phrygian cap gallbladder as a congenital and not as an acquired deformity an opinion shared also by Cesarina of Italy (1935) However Gross (1936) maintains that the puckering over of the tip of the gallbladder (Phrygian cap) is usually an acquired characteristic

Freely Suspended (Floating) Gallbladder The mode of attachment of the gallbladder to the gallbladder bed varies considerably As ascertained year after year in an inspection of some 75 bodies under dissection at the Daniel Baugh Institute of Anatomy at least two or three cases were encountered in which the attachment of the gallbladder to the liver was reduced to a width of a few centimeters attachment being effected in some instances solely by way of a mesentery like fold of peritoneum The mesentery of varying length (1 to 3 cm) may support the gallbladder and the cystic duct throughout their entire length or the mesentery may support only the cystic duct thus permitting the gallbladder to hang freely in the peritoneal cavity Because of its freely movable condition the gallbladder may become twisted—i e undergo torsion—and thereby cause a very serious and sudden occlusion of the cystic artery a condition which because of the loss of blood supply will lead to infarction of the viscus Gross (1936) and Corcoran and Wallace (1954) found this surgical emergency to have occurred most frequently in women over 50 years of age Long ago Brewer of Columbia University (1899) noted that in 100 bodies in the dissecting room 5 showed a freely movable suspended gallbladder a phenomenon which may be observed in any dissecting room today and which should be demonstrated to every student in his anatomy course Torsion of the gallbladder is discussed by Murray in the *British Journal of Surgery* 20 687 1933

Congenital Malpositions of the Gallbladder LEFT SIDED GALLBLADDER Abnormal positions of the gallbladder are extremely rare One of rarest of positional anomalies is the left sided gallbladder situated on the undersurface of

vestigations of 500 bodies at dissection such cystohepatic ducts were never observed. One of the graduate students of Jefferson Medical College (Schroy), in an examination of 50 plastic casts which he made of the extrahepatic bile ducts with vinyl acetate encountered 1 case in which it seemed as though a minute bile duct entered the upper part of the gallbladder directly but no similar phenomenon was noted in the 150 vinyl acetate corrosion casts of the intrahepatic bile ducts made by Healey and Schroy (1953).

Oddities. Grey Turner in his *Modern Operative Surgery* (1916) gives an illustration in which (a) the cystic duct opens directly into the duodenum, (b) accessory hepatic ducts open directly into the gallbladder, (c) the right and left hepatic ducts open into the gallbladder and the common bile duct leaves the gallbladder with an absence of the common hepatic and cystic ducts. Toupeeq of the Fatima Jinnah Medical College for Women, Lahore, Pakistan (1953) reproduces this illustration in his article on abnormalities of the cystic artery and the cystic duct. At the behest of W. Montague Cobb, Professor of Anatomy of Howard University, Washington, D.C., and editor of the *Journal of the National Medical Association*, the author discussed Toupeeq's paper in regard to the cystohepatic ducts stating that Turner's illustration should be deleted for in 400 bodies selectively studied as to the anatomy of the biliary ducts (200 of the author's, 50 of Schroy's in his M.A. thesis, 150 of Healey and Schroy's in plastic corrosion casts of the biliary tree) absolutely no evidence was found for the assertions made by Turner.

Subvesicular Bile Ducts. It is more than likely that some of the minute cystohepatic ducts observed by Mentzer and others in the region of the gallbladder belong to the subvesicular type of bile ducts first described by Haberland of Germany (1926). These filamentlike bile ducts emerge from the liver substance in the gallbladder bed and course superficially for a varying distance behind the gallbladder without ever entering the viscus. They were observed in many of the author's 200 dissections as a branch of the right hepatic duct (Figs. 59, 71, 77). Schroy (1952) found them in his vinyl acetate casts of the extrahepatic ducts, and Healey and Schroy (1953), in their extensive study of the segmental distribution of the intrahepatic biliary ducts as ascertained in 100 vinyl acetate corrosion casts, found the incidence of them to be as high as 35 per cent. Schmidt and Guttman of the Pathologic Institute of the City Hospital of Dortmund, Germany (1954), in a roentgenologic study of the intrahepatic ducts in 14 livers injected with a barium sulfate suspension, confirmed the existence of these filamentous subvesicular hepatic ducts. Their cholangiogram illustration of the ramus subvesicularis shows that it comes from the right hepatic duct (ramus ventralis) as previously ascertained by the author and by Healey and Schroy (1953). Simulating a nerve fiber or a connective tissue strand, these subvesicular ducts readily may be torn in cholecystectomy causing disconcerting postoperative leakage of bile.

Common Bile Duct. Congenital absence of the common bile duct has been reported but most of the cases with this defect have been instances of atresia rather than of congenital absence (Mentzer, 1916). As all experienced surgeons know, an absence of the supraduodenal part of the common bile duct occurs very frequently (Flint 14 per cent, Thompson 4 per cent, Johnston and Anson 20 per cent). Such cases represent but a developmental low union of the cystic duct with the hepatic duct at a point a bit below the superior border of the duodenum, for caudad to that point, the common bile duct is present (as

Developmental Peculiarities of the Biliary Ducts

True congenital absence of one or more of the hepatic ducts is not common in man although some instances of it have been reported As emphasized by Mentzer (1929) congenital atresias of the hepatic ducts are not true anatomic anomalies Bower of Philadelphia (1928) found 13 reported cases of an absence of all ducts with an average life duration of 70 days He reported a case with congenital absence of the gall bladder the cystic duct and the common duct the hepatic ducts being very small Of surgical importance is the fact that the common hepatic duct may be absent due to a low insertion of a large right hepatic duct into the common bile duct the cystic duct having previously joined the right hepatic duct (Fig 58) Johnston and Anson of Northwestern University (1952) encountered a similar case in 35 specimens The cystic right and left hepatic ducts may join together at the same point so that no common hepatic duct exists (Brewer 1900)

Cystic Duct That the gallbladder may empty directly into the hepatic duct or into the duodenum is an anatomic possibility Schachner of *Louisville Kentucky* (1916) found 9 true congenital absences of the cystic duct and 20 instances of congenital strictures of the cystic duct as reported in the literature Bower (1928) reported a case and collected 31 cases from the literature The cystic duct may drain into the left hepatic duct (Just Kehr) or into the right hepatic duct (Eisendrath) The latter variety was noted by the author on many occasions as illustrated in this atlas Kehr had a case of a double gall bladder in which one duct drained into the right the other into the left hepatic duct Reports in the literature of dual cystic ducts from a single gallbladder as found at operation have been very few Dressman (1908) reported a case of dual cystic ducts associated with an undivided gallbladder as did Kehr (1902) and Ruge (1908) More recently Shallow and Wagner of the Surgical Department of Jefferson Medical College (1952) removed a gallbladder with dual cystic ducts The latter were distinctly separated from their beginning at the neck of the gallbladder to the point where they individually drained into the common bile duct (unreported case the preserved specimen still available)

Cystohepatic Ducts These ducts commonly present in lower forms (as fish reptiles and birds) and supposedly existing in man drain bile from the liver directly into the side of the gallbladder or into the cystic duct along its course Mentzer of San Francisco (1929) is firmly convinced of their existence in man having encountered them and having verified their histology in microscopic sections in 8 of 96 necropsies Mentzer claims that most channels between the liver and the gallbladder are veins but some are definitely minute bile ducts They are important to the surgeon for they are the ducts most commonly severed Because of their position and small size they are difficult to recognize yet when injured they may *lead readily to postoperative leakage* of bile with resultant bile peritonitis During anesthesia according to Mentzer the flow of bile is decreased and not sufficient drainage from the severed ducts is present to recognize their presence He stated I know of no way in which these ducts may be identified at the operating table Common in lower vertebrates (Mentzer) and mammals as calves and pig (Boyden) these cystohepatic ducts should be investigated anew for very little has been recorded regarding their presence in man Eisendrath (1918) reported their occurrence in man and Corcoran and Wallace (1954) directed attention to them claiming that a severance of them might result in persistent postoperative bile drainage with resultant bile peritonitis In the author s in

bile ducts were recognized in cholangiograms in 69 cases (7 5 per cent) Furthermore in 31 of 46 selected cases intrahepatic stones were demonstrated Ericsson and Rudhe of the Karolinska Institute Stockholm Sweden (1954) have since extended our knowledge of the normal roentgen anatomy in infancy and childhood (*Acta Chir Scand* 107 275 1954) These authors maintain that there is good reliable correlation between cholangiographic findings and contemplated surgery Roentgenograms should be taken as soon as the gallbladder can be identified and intubated for the risk of laparotomy and cholangiography of the normal biliary tract is negligible Cholangiographic visualization of the biliary tree will obviate the necessity of further exploration and prevent trauma for if there is an obstruction or an anatomic anomaly roentgenograms will visualize the site of its location

These so-called accessory ducts as will be shown later occur for the most part in the cystic triangle of Calot where they join the hepatic duct or the right branch thereof and in some instances join the cystic and common bile ducts Whereas the accessory hepatic duct in the cystic triangle is predominantly single quite frequently 2 may be present An accessory hepatic duct may produce a bizarre baffling and surgically dangerous relationship of the cystic duct Thus when an accessory hepatic duct leaves the right hepatic duct and joins the cystic duct an anastomosis is effected between the two ducts Both Flint and Thompson observed such an anastomosis The case encountered by the author was complicated by the fact that the right hepatic artery passed through the loop made by the anastomosis (Fig 98)

Contrary to the general belief that accessory left hepatic ducts do not occur is the fact that they have been encountered repeatedly (Descomps and de Lalaubie 1910 McWhorter 1923 Beaver 1929 Moosman and Coller 1951 Michels 1951 and Healey and Schroy 1953) On two occasions the author found an accessory left hepatic duct one joining the common hepatic duct (Fig 10) the other the common bile duct (Plate III No 46) Healey and Schroy (1953) found 2 instances of them in vinyl acetate corrosion casts of the biliary tree the ducts representing cases in which there was no union of the medial and lateral segmental ducts inside the liver

Accessory or aberrantly placed hepatic ducts occur with a greater frequency than is generally appreciated as is evident from the accompanying table

TABLE 4 ACCESSORY (ABERRANTLY PLACED) HEPATIC DUCTS

Author	Number of Specimens	Number of Accessory Ducts	Percentage Occurrence
Brewer (1900)	100	1	1
Ruge (1908)	43	11	26
Descomps and de Lalaubie (1910)	50	10	20
Piquand (1910)	40	10	25
Flint (1923)	200	29	15
McWhorter (1923)	37	1	3
Beaver (1929)	57	5	9
Thompson (1933)	50	3	6
Michels (1951)	200	36	18
Moosman and Coller (1951)	250	39	16
Johnston and Anson (1952)	35	11	31
Healey and Schroy (1953)	100	28	28

shown in many of the author s illustrations)

Kehr of Germany (1903) described a case of reduplication of the common bile duct and collected 8 reports from the literature Courvoisier (1890) recorded 10 cases of division or double insertion of the common bile duct and reported a case in which one choledochus entered the duodenum while the other entered the transverse colon A termination of the common bile duct into the stomach of man has been reported by Laennec and by Bleifuss (cita Mentzer) In this connection it is interesting to know that in 1935 Swartley and Weeder (the former an instructor of anatomy at the Daniel Baugh Institute of Anatomy for over 30 years) reported and rectified at operation the only case ever reported of an observed choledochus cyst with a double common bile duct

According to Boyden (1932) 16 cases of congenital doubling and 5 cases of abnormal insertion of the common bile duct have been reported in the literature In an investigation of 10 000 livers (2 500 cats and about an equal number of calves pigs and lambs) Boyden (1926) did not encounter a single case of double choledochus Later (1932) however he observed a case in an adult male in whom the common hepatic duct divided into a normal common bile duct and into a hepato-enteric duct which inserted on the pars superior of the duodenum (1 5 cm from the pylorus) the two ducts inserting 8 cm apart Boyden explains the anomaly on the basis of an early and aberrant subdivision of the primitive hepatic furrow in the sense that most of the pars hepatica remained with the gastric part of the gut developing its own hepato enteric duct emptying into the region of the pylorus whereas the pars cystica moved caudally to its usual site on the duodenum

Accessory (Aberrantly Placed) Hepatic Ducts. What were regarded formerly as accessory hepatic ducts *henceforth are to be termed aberrantly placed extrahepatic ducts, i e , functionally they are not accessory or additive ducts but represent bile ducts that failed to join the biliary tree inside the liver,* as shown by Schroy (1952) in his 50 vinyl acetate casts of the extrahepatic bile ducts and by Healey and Schroy (1953) in their vinyl acetate corrosion casts of 100 human livers

The monograph on cholangiography of the hepatic ducts by Olof Norman of the University of Lund (1951) should be available to every radiologist (*Act Rad*, Suppl 84 1951) Therein is clearly portrayed for the first time in all of its aspects the roentgen anatomy of the entire biliary tree The basis of the roentgen anatomy of the intrahepatic biliary tree was established by Hjortsjo (1948) Elias and Petty (1952) and Healey and Schroy (1953) as seen in cholangiograms and confirmed in vinyl acetate corrosion casts Norman has shown that the gross anatomy of any biliary tree now can be reproduced by cholangiograms provided these are made at different angles (anteroposterior lateral and oblique) to ascertain the exact course of the respective intra hepatic duct He has shown that it is now possible to decide by a cholangiogram to which segment of the liver a given bile duct branch belongs In regard to the so-called accessory hepatic ducts (i e aberrantly placed low extra hepatic hepatic ducts) he stated In these cases then there was no question of an accessory duct but of an anomalous course of an otherwise anatomically well defined branch Ductal anomalies according to Norman are not only of anatomic and academic interest for as soon as a branch enters at a level below the normal confluence of the main intra hepatic ducts it is also of practical surgical import and falls into the operative field In 919 patients anomalies of the

bile ducts were recognized in cholangiograms in 69 cases (7 5 per cent) Furthermore in 31 of 16 selected cases intrahepatic stones were demonstrated Ericsson and Rudhe of the Karolinska Institute Stockholm Sweden (1954) have since extended our knowledge of the normal roentgen anatomy in infancy and childhood (*Acta Chir Scand* 107 275 1954) These authors maintain that *there is good reliable correlation between* cholangiographic findings and contemplated surgery Roentgenograms should be taken as soon as the gall bladder can be identified and intubated for the risk of laparotomy and cholangiography of the normal biliary tract is negligible Cholangiographic visualization of the biliary tree will obviate the necessity of further exploration and prevent trauma for if there is an obstruction or an anatomic anomaly roentgenograms will visualize the site of its location

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Congenital Obliteration (Atresia, Stenosis) of the Bile Ducts While a discussion of the atretic conditions of the biliary system is beyond the scope of this atlas a few items pertaining to the topic are well worth recording As stated by Gross (1953) in his recent text *The Surgery of Infancy and Childhood* the name of John Thomson of England always will be associated with congenital biliary obstruction for he was among the first (1892) to present an analysis of 50 cases Holmes of Johns Hopkins University (1916) reproduced 30 of Thomson s sketches and added diagrammatic representations of all the main atretic conditions he encountered in a survey of 100 recorded cases Fully four pages are devoted to an illustration of reported atretic conditions with a mention of the respective author in most instances

Holmes described a case first observed in an infant boy at the age of 7 weeks The atretic condition consisted in an anomalous arrangement of the hepatic ducts absence of the common duct and impervious cystic duct with abnormalities of the gallbladder Holmes noted that in over 16 per cent of all recorded cases of atresia of the bile ducts both the cystic duct and the hepatic duct were essentially normal and communicated with each other and on the basis of this fact suggested that operative relief in these cases is theoretically possible

It was Ladd of Harvard University (1927) who performed the first successful operation for relief of congenital atresia In a paper read before the section on Diseases of Children at the 79th *Annual Session of the American Medical Association* in Minneapolis June 14 1928 Ladd stated that contrary to statements found in textbooks on pediatrics surgical treatment can be undertaken with hope of success in atretic conditions In his series of 20 cases 11 were operated on of these 8 were amenable to surgical treatment there being 6 who had complete recovery

Outstanding in accomplishments and pioneer in character in America is the *Children s Hospital of Boston* set up by William F Ladd of Harvard University and established as a separate unit to such an extent that pediatric surgery might well become a separate departmental entity in surgery in all our medical schools Up to 1952 according to Gross the present departmental head a total of 183 babies had been examined for biliary obstruction Of these 119 had obliteration of the intrahepatic ducts the main hepatic duct or all the extrahepatic ducts conditions for which nothing could be done surgically Of 146 babies who had atresia of one or of all the extrahepatic ducts 27 were found to have some part of the ductal system that communicated with the liver and accordingly could be joined surgically to the duodenum

The atretic conditions encountered in the 146 babies according to Gross comprised the following types (1) gall bladder hepatic duct and cystic duct patent common duct obliterated 16 cases (2) gallbladder normal hepatic duct patent other extrahepatic ducts obliterated 10 cases (3) common duct patent hepatic duct patent in upper part but atretic below 1 case (4) gall bladder and all ducts atretic, 52 cases (5) gallbladder containing a mucoid material all ducts atretic 47 cases (6) gallbladder connected with duodenum hepatic duct atretic 19 cases (7) intrahepatic ducts atretic all extrahepatic ducts normal 1 case Gross gives sketches of the various types and states that the first three types are operable the others are not

From the vast experiences at the Children s Hospital Gross presents the following optimistic outlook

> The list of fatal cases is long and most discouraging yet the fact remains there has been an over all salvage rate of 26 per cent of the 198 babies who were treated (medically or surgically) for obstructive jaun

duct in the early months of life This ray of light makes it evident that surgical exploration should be undertaken for all babies with biliary obstruction in the hope of picking out and saving those who have a remediable situation (The Surgery of Infancy and Childhood Philadelphia Saunders 1953)

Gray Du Shane and Hennegar of the Mayo Clinic (1948) reported a case of cholecystogastrostomy for congenital atresia of the common bile duct in a female infant 8 weeks old with beneficial results They stated that treatment was successful in 15 cases in the literature these having congenital atresia of the common bile duct Of patients with congenital atresia of the bile duct 60 per cent were males Amberg and Zuschlag (1944) reported 18 cases of congenital obstruction of the extrahepatic bile passages seen at the Mayo Clinic Penberty and Benson of Wayne University (1938) had a case of a female infant with 8 months of obstruction of the common bile duct due to inspissated bile which they were able to cure by irrigation

Craig of Harvard University (1950) reported that of 141 infants whose death was due to erythroblastosis only 14 per cent showed severe anatomic damage Ten had necrosis of the liver 4 had necrosis and fibrosis and 2 had actual cirrhosis

Erythroblastosis Fetalis At present it is well known that erythroblastosis fetalis (icterus gravis neonatorum) often is accompanied by jaundice and may present a clinical picture similar to that of biliary obstruction (Lightwood and Bodian 1946 Craig 1950) Due to the tremendous destruction of red cells occurring in this disease the bile ducts may become plugged up inspissated with accumulated pigment debris Hsia Patterson Allen Diamond and Gellis (1952) in their report of 156 cases of prolonged obstructive jaundice in infants noted that in 15 per cent of these cases erythroblastosis was responsible for an inspissation of the bile duct Gross (1953) was able to wash out the inspissation plug from the duct by irrigation and thus cure 26 of 35 cases Ericsson and Rudhe of Sweden (1954) found cholangiography to be a very effective and reliable means to determine the absence or the patency of the intrahepatic and the extrahepatic ducts in infants Their paper contains eight cholangiograms depicting normal and abnormal conditions of the biliary tree in infants from 3 days to 6 weeks of age In 8 of 11 cases it was possible to perform cholangiography there being in their experience a very good correlation between it and surgery

For further data on atretic conditions of the biliary system the reader is referred to the classic textbook of Gross in which obstructive jaundice and the miscellaneous conditions of the liver and the bile passages are discussed fully including diagnosis and current treatment of cases

Pancreatic Bladder Aberrant Pancreatic Tissue and Annular Pancreas

Pancreatic Bladder This odd organ was first described clearly by De Graaf (1664) in the cat and thus far has been observed only in this animal some 25 cases having been reported in the literature (Mayer 1815 Gage 1879 Miller 1904 1905 1910 Heuer 1906 Dresbach 1911 Johnson 1914 Larsell 1920 Beckwith 1921 Boyden 1926 Bean and Dreyer 1927 and Higgins and Wilhelmj 1930)

The pancreatic bladder may be situated to the right or to the left of the normal gallbladder or it may be behind it Its duct may join the pancreatic duct or the duct of Wirsung with subsidiary other pancreatic duct connections The walls of the two bladders are often fused with connective tissue but their cavities are separate Bean and Dreyer reported a case in which the smaller vesicle was embedded in the wall of the primary

one In Heuer's case the pancreatic glandular tissue extended cephalad along the choledochus to about the middle of the gallbladder, each band possessing its own duct

Miller of the University of Wisconsin found 8 instances of pancreatic bladders In 2 cats an accessory lobe of pancreatic tissue followed the choledochus to the gallbladder nearly reaching it in one case Miller suggested that the origin of the pancreatic bladder and duct was brought about by the loss of pancreatic tissue in this lobe, leaving the duct lying parallel with the ductus choledochus while the free end expanded into the bladder Larsell while at the University of Wisconsin, found a pancreatic bladder in a young cat that was slightly larger than the gallbladder extending beyond the fundus of the latter for 6 mm It was connected with the ductus pancreaticus by a main duct that crossed the common duct Just before uniting with the latter the main duct gave off a branch that communicated with the axial duct of the head of the pancreas Cora Jipson Beckwith of Vassar College Poughkeepsie N Y (1921) described a pancreatic bladder in the cat that was somewhat smaller than the gallbladder and that was situated behind it Its duct opened into the duct of Wirsung after the union of the two divisions of the pancreatic duct Peculiar in her case was the cross connection between the duct from the pancreatic bladder and the cystic duct the latter's lumen being closed above the communicating point There was no essential difference in the mucosa lining of the two bladders

Boyden (1922 1929) stated that in contrast with the frequency of the double gallbladder in cat (as in sheep pigs and cattle) the pancreatic bladder occurs very rarely even in cat for he found only 6 cases in an examination of 2 600 cats In a sample he reported (female cat) the pancreatic bladder was situated to the left of the gallbladder and was larger The walls of the two bladders were fused throughout but the cavities and the ducts did not communicate Following Miller (1910) he interpreted the pancreatic bladder as representing a persistence of the left ventral pancreas which undergoes an aberrant elongation in the direction of the gallbladder the terminal portion of the lobe dilating to form the gallbladder the proximal end atrophying leaving only the duct Bremer (1923) interpreted the cat's pancreatic bladder as representing the caudal half of the primary liver diverticulum while Lewis (1911) regarded it as a development from the left lobe of the ventral pancreas

While pancreatic bladders have thus far been found only in cats many of the higher animals may have aberrantly placed pancreatic tissue Boyden (1925) found portal lobes of the ventral pancreas in 15 pigs none of which however extended beyond the porta hepatis In 3 sheep they paralleled the course of the bile duct from the duodenum to the gallbladder in cats where 40 portal lobes were encountered 14 of them extended to the neck of the gallbladder In mammals, then pancreatic tissue via portal lobes may attain a secondary connection with the biliary tract

At the Mayo Clinic Mann (1922) observed two cases and Higgins (1926) one case of accessory pancreatic tissue occurring in the wall of the gallbladder of the dog Comparably situated pancreatic tissue in the human gallbladder according to Thorsness (1940) was observed on only a few occasions (von Hedry 1924 Cogniaux 1928 Poppi 1934) his own being on the neck of the gallbladder

Aberrant Pancreatic Tissue in Man Exclusive of the pancreatic bladder and the annular pancreas (the latter a developmental anomaly) aberrant pancreatic tissue may be defined as that occurring in a region other than that of the normal pancreas being independent of … lat

ter s blood supply and morphologic contours Most pancreatic nodules (accessory pancreases) are small averaging 1 cm in diameter the largest rarely exceeding 5 cm (Horgan 1921) They have a whitish opaque color Structurally they show pancreatic acini islets of Langerhans and dilated ducts although the latter may be absent entirely or only in part

Extensive reviews on aberrant (accessory) pancreatic tissue are those of Oppel (1900) Warthin (1904) Opie (1910) Benjamin (1918) Horgan (1921) Boyden (1925) Hale (1926) Higgins (1926) Branch and Gross (1935) Thorsness (1940) and Pearson (1951) Klob (1859) and Zenker (1861) are cited as having described the first cases of an accessory pancreas in man Warthin (1904) found 47 cases reported in the literature and added 2 that he had found Horgan of the Mayo Clinic (1921) calculated that in the interval between 1904 and 1921 an additional 31 cases were recorded Hale of Wilmington Ohio (1926) gave a list of 62 references and reported a case noted in the pylorus of an infant Thorsness of the Denver General Hospital Colorado (1940) found 347 reported cases and described a nodular mass in the neck of the gallbladder Pearson of Long Beach Calif (1951) removed aberrant pancreas from the ampulla of Vater and listed 97 references in his review of the literature

Aberrant pancreatic tissue in man occurs frequently in the gastro intestinal tract Opie (1910) found 10 instances in 1 800 necropsies Horgan (1921) found 2 instances in 314 cases in which the entire intestinal tract was opened at autopsy Poppi (1935) calculated its frequency to be 1 89 per cent in 4 076 autopsies According to Thorsness (1940) aberrant pancreatic tissue when it occurs is found most commonly (90 per cent) in the foregut as in the wall of the stomach (Best 1935) or the small intestine (submucous intramural subserous or invading all three layers) When it occurs in the wall of the pylorus it may be sufficiently large to cause obstruction (Hale 1926 Cogniaux 1928) or to cause ulcers (Cohen 1922) Commonly accessory pancreatic tissue is found at the tip of some diverticulum of the gastro intestinal tract especially the duodenum as described by Poppi of Italy (1935) in 25 cases and recorded long ago by Brunner (1899) Horgan (1921) maintains that the accessory pancreatic tissue may be the actual cause of the diverticulum The tip containing the pancreatic tissue may become attached to the abdominal wall or to the intestine forming a band or a loop through which a coil of the small intestine may pass leading to obstruction and strangulation An accessory pancreas may lead to intussusception of the jejunum (Benjamin 1918) On numerous occasions it has been associated with chronic intestinal inflammation (Warthin 1904 Mayo Robson 1908 Opie 1910 Gibson 1912) and according to Eloesser (1908) it may even be a causative factor in cancer In the ampulla of Vater it may produce obstruction of the common and the pancreatic ducts (Pearson 1951) Repeatedly Meckel s diverticulum has been found to contain gastric mucosa and pancreatic tissue (Nauwerk 1893 Hill and Cohn 1937 Danzis 1938)

Outside of the gastro intestinal tract accessory pancreas may be found in the adjacent peritoneal formations (9 cases) and may extend to the liver (Boyden 1922) It has been found adjacent to the umbilicus (Wright 1901) and in the fat of the great omentum (Horgan 1921) Quite frequently an accessory pancreas has been found in the capsule of the spleen (3 cases Branch and Gross 1935) According to Higgins (1926) pancreatic tissue is found in the spleen more frequently than in hepatic tissue Schnyder (1926) having found liver tissue in the

spleen of a newborn Despite what is known regarding the pancreatic bladder of the cat as a juxtaposed organ of the gallbladder instances of observed accessory pancreatic nodules in the human gallbladder and its duct have been very rare only several cases having been reported to wit in the wall of the cystic duct (Otschkin 1916), in the wall of the gallbladder (von Hedry 1924 Cogniaux 1928 Poppi 1935) and in the neck of the gallbladder (Thorsness 1940) According to Higgins (1926) pancreatic tissue has never been found in the rectum or the colon

Origin of Accessory Pancreas Lewis and Thyng of Harvard University (1908) claimed that knoblike intestinal diverticula are the probable source of accessory pancreases as observed in models of pig embryos In 1912 Lewis found an accessory pancreas that developed from a longitudinal epithelial bud in the wall of the stomach of a 19 mm embryo Bremer of Harvard University (1923) maintained that the original hepatic diverticulum is of dual potentiality containing both pancreatic and hepatic elements The cranial one half of the embryonic hepatic diverticulum *is potentially hepatic the caudal one half* is pancreatic Zenker (1861) one of the discoverers of the accessory pancreas and originator of the Zenker fixation fluid assumed that accessory pancreatic tissue arose from an accessory pancreatic anlage In his report to the physicians and surgeons of Detroit and Ann Arbor Warthin (1904) stated that

> It is probable that accessory pancreatic tissue is formed from lateral budding of rudimentary pancreatic ducts as they penetrate the intestinal wall the mass of pancreatic tissue thus formed being snared off and carried by longitudinal growth of the intestine either upward or downward (*Physician & Surgeon* 26 337 1904)

After prolonged investigation Boyden (1925) concluded that the aberrant pancreatic lobes in sheep pig and cat appeared to be modifications of a filamentous extension of the left lobe of the ventral pancreas along the hepatoduodenal ligament in the hepatic region Horgan (1921) however maintains that accessory pancreatic tissue *cannot be regarded as embryonic rests* While the gland is growing and changing its positions in the primitive mesentery the latter is also growing and pulling in the opposite direction In this manner a bud may be attached to the mesentery and be pulled away from the gland Thus Warthin explains his case of an accessory pancreas in the fat of the omentum The moment a bud finds a suitable environment it will grow in structure and have a separate function

According to Oppel (1900) pancreatic tissue occurs from the cyclostomes to man except in *Amphioxus lanceolatus* In the animal kingdom pancreatic glandular tissue exists in the form of (1) single or multiple masses of glandular tissue embedded between the muscularis and the serosa in the wall of the stomach and the duodenum or both and having one or more short or long ducts for each mass (2) one or several glandular masses spread out between the layers *of the mesentery and attached* to the stomach the duodenum or the intestine and emptying through one main excretory duct from each mass (3) numerous small or very small glands in fine cordons dispersed through the entire cavity between the layers of the mesentery (4) numerous small or very small glands growing along the blood vessels enveloping them like a sheath and advancing with the blood vessels in the liver and the spleen interweaving the liver as it follows the vessels in their various directions or into the spleen by entering at the hilum with the blood vessels or spreading over the splenic capsule from the hilum

Thus after what has been recorded it is quite obvious that the occurrence of aberrant pancreatic tissue in man is

readily explicable on the basis not only of ontogenetic but also of phylogenetic development In lower vertebrates the liver and the pancreas are less markedly delimited and in certain animals lose their identity in a hepatopancreatic or intestinal gland In their study on peritoneal absorption in teleosts Mackmull and Michels (1932) showed that in the liver of the cunner (*Tautogolabrus adspersus*) branches of the hepatic and portal veins and the bile ducts are surrounded by pancreatic tissue About smaller vessels the pancreatic sheaths (gland areas) are composed of one or two rows of cells about larger vessels as many as 10 rows are often present The gland areas are delimited from the liver cells by a capillary space (periglandular capillary) lined with reticulo endothelial cells which after injection of carbon exhibit marked phagocytic activity the freed carbon laden macrophages migrating into the gland areas Normally the connective tissue about the gland areas exhibits foci of hemopoiesis eosinophils of the diffuse granular type being abundant in the periglandular capillaries and in the gland areas

In studying the problem phylogenetically Weber (1905) was the first to postulate the existence of a ring or band of hepatopancreatic tissue placed about the intestine in lower forms it being caudad to the respiratory tract but in vertebrates being caudal to the intervening expansion of the stomach The ring consists of transverse rows of multiple intestinal epithelial buds which potentially could form either pancreatic or liver tissue depending on extrinsic factors such as their relation to veins and to the celom In this manner Weber explained existent differences of the liver and of the pancreas in birds and mammals differences of developmental position of the ventral and dorsal pancreases and their ducts and the presence of accessory pancreatic tissue

With the postulate of Weber in mind it is readily conceivable that in ordinary development the potency to form pancreatic or liver tissue is lost in areas above or below the original hepatopancreatic ring But such potency may be retained for the entire abdominal portion of the foregut thus explaining the presence of pancreatic tissue in its derivatives (stomach duodenum jejunum ileum Meckel s diverticulum spleen gallbladder and biliary duct system)

Annular Pancreas In this anomaly the head of the pancreas forms a complete ring around the descending duodenum the narrow part of the ring lying anterior and to the right of the duodenum If the pancreatic ring is not complete the defect occurs on the anterior surface of the duodenum Different from the annular pancreas is the anomaly known as the lesser pancreas it being formed when the uncinate process develops as a separate structure A true annular pancreas occurs very rarely about 50 cases having been reported in the literature (Lehman 1942) It is found nearly exclusively in males (Millbourn 1950)

The annular pancreas was described first by Tiedemann Professor of Anatomy at Heidelberg University Germany in 1818 Ecker (1862) gave it the name annular pancreas Cases of annular pancreas have been reported by Schirmer (1893) Letulle and Nattan Larrier (1898) Vidal (1905) dos Santos (1906) Lecco (1910) Lerat (1910) Opie (1910) Baldwin (1911) Smetana (1928) Howard (1930) Brines (1931) Zech (1931) McNaught (1933) McNaught and Cox (1935) Truelson (1940) Lehman (1942) Goldyne and Carlson (1946) Nedelec (1946) Brown Bingham and Cronk (1948) Burger and Alrich (1949) Dubost Allary and Sullivan (1950) Haden (1950) Millbourn (1950) Olmacher and Marshall (1950) Orts and Duenas (1950) Ravitch and Woods (1950) Anserson and Wapshaw (1951) Bickford and Williamson (1951) Conroy and Woelfel (1951) Payne

(1951) Wakelay (1951) Gonzales Lopez and Paz (1952) Shapiro Djvrick and Gerrish (1952) Silvis (1952) McPhee (1953) Swynnerton and Tanner (1953) Temsykokski, Stevens and Izzo (1953), Wilson and Bushart (1953) Skapinker (1954) and others

In their report of a case McNaught and Cox of the Stanford University School of Medicine (1935) presented a simple method for visualizing the duct system They noted that, in 88 per cent of 40 reviewed cases the duct of the annular pancreatic ring was part of the duct of Wirsung this being a strong indication that the annular pancreas is a developmental anomaly of the ventral pancreas anlage Lehman of the University of Virginia School of Medicine (1942) reported a case with a correct tentative preoperative diagnosis in a white male 23 years of age with duodenal obstruction According to his review 48 cases of annular pancreas have been recorded in the literature and of these 10 were operated on An analysis of these showed that there is a constant anterior point of origin of the duct (of the ring) which subsequently courses to the right over the duodenum then posteriorly and to *the left behind the duodenum* finally entering the head of the pancreas in close relation to the common duct to terminate into the main pancreatic duct

Clinically considered according to Lehman an annular pancreas may be sufficiently large and sufficiently extensive to necessitate surgical intervention In addition to producing a narrowing of the lumen of the duodenum at the site of the encircling band (duodenal stenosis) it causes a dilatation of the duodenum accompanied by a thickening of its wall cranial to the constriction This dilatation may progressively involve the stomach producing in the latter a hypertrophy of its walls (Millbourn 1950) The surgery of the annular pancreas is discussed by McNaught and Cox (1935) Lehman (1942) Ravitch and Woods (1950) Payne (1951) and Skapinker (1954)

Skapinker of the University of Witwatersrand Johannesburg South Africa (1954) collected from available literature 45 cases of annular pancreas and in table form listed author date, operation and result of operative procedure of each case In the case he reported (Bantu woman aged 22) the patient was in a state of tetany due to alkalosis which occurred as a result of persistent vomiting this being the outstanding symptom in the majority of cases reported According to Skapinker the diagnosis of annular pancreas readily can be made preoperatively by roentgen examination which reveals a dilated duodenum with almost complete obstruction (arrest of barium in the second part of the duodenum) Conditions to be considered in differential diagnosis are duodenal ileus polyp or diverticulum of duodenum and malignant tumor In children it may be somewhat more difficult to differentiate the condition from pyloric stenosis or duodenal atresia He cites the case of Shapiro Djvrick and Gerrish (1952) in which there was incomplete rotation of the colon and mongolism To avoid the *danger of damaging the duct* when cutting the ring of annular pancreas Skapinker advocates a retrocolic duodenojejunostomy as the most satisfactory by pass operation

Whether a third duodenal papilla is always present in annular pancreas as theoretically postulated by Siwe (1926) remains to be determined The occurrence of three duodenal papillae has been reported by various authors (Schirmer 1893 Letulle and Nattan Larrier 1898 Baldwin 1911) but the phenomenon is not necessarily associated with the presence of an annular pancreas

Embryology The annular disposition of the pancreas is readily explicable on an embryologic basis As previously stated the pancreas arises from the duodenal wall by two anlagen one dorsal,

the other ventral The ventral anlage consists of two parts left and right Or dinarily when the duodenum rotates to the right the right half of the ventral pancreas is carried around the right side then dorsal to the duodenum where it fuses with the dorsal anlage to form the caudal segment of the head of the pan creas The left half of the ventral pancreas generally atrophies If it per sists and extends to the left ventral to the duodenum to join the main mass of pancreatic tissue or if there is an excess growth of the right half of the ventral pancreas an annular pancreas is formed

The Liver and the Gallbladder in Hepatoscopy and Religious Rites

From a historical point of view it is interesting to note that in antiquity and in the era of magic medicine the liver was regarded as the seat of the soul and the gallbladder played an important role in hepatoscopy and religious rites Jas trow Professor of Semitic Languages at the University of Pennsylvania has writ ten two books on the subject the one in English having been published by the Macmillan Company New York (1912)

As ascertained by Jastrow in his exten sive studies divination through signs and parts of the liver can be traced back to the most ancient period of Babylonian and Assyrian history (c 3000 B C) The theory of hepatoscopy as practiced by the Babylonian priests is based on the supposition that the liver was a divine organ in the sacrificial animal (sheep) which took on the character of the soul of the deity to whom the animal was offered The liver was regarded as the central vital organ in the animal as it received all the blood the latter being the carrier of every vital function The liver was thought to be the seat of all forms of mental and emotional activities —in short the seat of the soul When a person was mortally wounded he was spoken of as struck in the liver and the punishment of Prometheus whose liver was gnawed by the vulture as re corded by Aeschylus is based on the same primitive view The rite of divin ing the future through signs on the liver led to an early study of its anatomy In his paper presented before the College of Physicians of Philadelphia Novem ber 6 1907 Jastrow stated

The parts of the liver to which in divina tion rites special attention was paid were the various lobes the gall bladder the portal vein the gate of the liver the two appendages to the upper lobe (known as the *lobus caudatus*) and to the markings on the liver lobes due to the traces on the sur face of the liver of the subsidiary gall ducts that gather the gall from the liver into the gall bladder and to the subsidiary vein ducts distributing the blood from the larger por tal vein through the liver No two livers naturally presented the same phenomena— as little as two leaves of a tree—and the innumerable variations in the character of the lobes in the gall bladder and various ducts and in the markings on the liver furnished a boundless field across which the fancy of the divining priests could roam at will

To instruct students the Babylonian priests made models of the liver of the sheep A clay model of this kind is in the British Museum with a divination text of the period of Hammurabi (c 2000 B C) Found near Piacenze Italy in 1877 was a comparable bronze model of the liver used in Etruscan divination (c third century B C) Both models to gether with a diagram of a sheep s liver (Kabittu) showing modern anatomic terms and their Babylonian equivalents are illustrated by Jastrow in the *Trans actions of the College of Physicians* 29 1907 In the clay model the posterior surface of the liver is divided into squares with a hole in the middle of each square Into these holes the haruspex or extispex placed pegs to prognosticate as deemed most suitable for the occasion

This early study of the anatomy of the liver through signs and parts thereof

gave rise to such terms as the right and left wings of the liver (lobes) the river of the liver (umbilical fossa) the river at the edge of the liver (fossa vesicae felleae) the finger of the liver (pyramidal process of the caudate lobe) the bitter part (gallbladder) The hepatic duct was the outlet the common bile duct was the yolk or junction point the transverse fissure was the gate or crucible The portal vein was *the strong* and the gallstone was a knot

Jastrow calls attention to the fact that in the Pentateuchal codes the phrase that which hangs over the liver occurs 10 times (Exodus xxix 13 and 23 Leviticus iii 4 10 15 vii 4 viii 16 and 25 ix 10 and 19) The biblical phrase is generally rendered as the caul above the liver and is the Hebrew equivalent for the fingers of the liver In each case in which the phrase occurs it is stipulated that this part of the liver is to be burned in animal sacrifice (sin offering guilt offering and peace offering) Since the spirit of all Pentateuchal codes is firmly opposed to sorcery incantation and divination of all kinds Jastrow concluded that

> it is not surprising to encounter a provision which is intended to be a protest against the Babylonian view that made sacrifice a means for securing the aid of a god in divining the future

The high official status to which the haruspices had brought their cult is shown in the following passage from the Bible

> For the King of Babylon stood at the parting of the way at the head of the two ways to use divination he made his arrows bright he consulted with images he looked in the liver (Ezekiel xxi 21)

The right of divining through the liver of sacrificial animals not only was practiced among the Babylonians the Etruscans and the ancient Chaldeans but also for centuries had constituted a widespread cult among the Romans and the Greeks The Latin word haruspex or soothsayer is a derivative of the Chaldean har which means liver It is well known that the augurs in Rome generally were imported from Etruria The source of Greek hepatoscopy most probably is to be traced directly to the Babylonians rather than to the Etruscans According to Jastrow traces of the theory underlying the rite of hepatoscopy are to be found among the Hebrews and the Arabs as well as in India and China According to Torrey of Yale University the story is told in Arabic literature that the prophet Mohammed on an occasion of great sorrow wept all night as though his liver would break In Borneo, the animal of sacrifice is the pig in Burma it is a fowl or a pig while in Uganda the livers of goats usually are chosen

Bouche Leclerg (1906) in his work *Histoire de la Divination dans L Antiquite,* stated that the liver was regarded as the organ of revelation par excellence From the fact that the liver was consistently employed as the sole organ of divination in Babylonia and Assyria for over 3000 years Jastrow concluded that the religious ceremony was not regarded as a meaningless superstition or fraud and that the rite was never abused by the priests To the contrary unfavorable decisions based on the inspection of the liver not only were rendered openly but also in some instances were checked repeatedly by reinspection Jastrow states that most of the interpretations of the signs of the liver had to do with public events but they could be applied also to private affairs

> Thus if the gall bladder was swollen on the right side it pointed to an increase in the strength of the king s army and was therefore interpreted as a favorable sign in general while the swelling on the left side prognosticated the success of the enemy and was therefore an unfavorable sign If the gall bladder lay tightly embedded in the gall bladder groove it meant if on the right

side that the king s army would be in the firm grasp of the enemy and [was] therefore to be regarded as an unfavorable symptom if however the left side of the gall bladder was tight that the enemy would be kept as a prisoner and therefore a favorable symptom for the king s army If the biliary duct was long it pointed to long life if the hepatic duct was well enclosed in the gate of the liver it meant success in battle if however it lay above and beyond the hepatic duct it indicated a position exposed to the attack of the enemy If the finger shaped appendix (*processus pyramidalis*) was broad it was interpreted as joy if it was small while the other appendix—usually small—was large it pointed to an inversion of the natural order The son would be mightier than the father the servant would prevail against his master i e in general that the small would be great and the great submit to the small Gallstones designated as knots are also not infrequently mentioned in the divination texts and in connection with other symptoms are either favorable or unfavorable

Another of Jastrow s divination findings is the following

If the gallbladder is cleft from left to right and if a gallstone is situated at the top of the split then the leader of your men will capture the enemy (*Die Religion Babyloniens und Assyriens 1912*)

Jastrow states that although the anatomic nomenclature for Greek and Roman hepatoscopy was not the same as that of the Babylonians the parts and the signs on the liver used for interpretation were practically identical

Thus in the passage in the Prometheus of Aeschylus (line 495 seq) in which Prometheus recounting among the benefits that he conferred on mankind the art of divining through the sacrificial animal the gall bladder and the *processus pyramidalis* are singled out as particularly significant while in a passage in the Elektra of Euripides (line 826 seq) the gate of the liver is added As in Babylonia the enlarged character of the *processus pyramidalis* so that it sometimes appeared to be double was a good sign pointing to enlargement of power while the absence real or apparent of this appendix was an unfavorable symptom So again the black color of the gall bladder was an unfavorable sign just as in Babylonian omen texts the black color always involved an unfavorable augury

References to the gallbladder in connection with sacrificial rites or religious rules as ascertained by Boyden (1926) comprise the following Pliny mentions the fact that on the day of Emperor Augustus s naval victory at Actium (31 B C) a double gallbladder was found in the sacrificial victim (cited by Jastrow 1912) In the Talmud (completed about A D 500) which contains the ritualistic laws of the orthodox Jew it is definitely stipulated under what conditions an animal is kosher i e fit for food or is terefah i e unfit for food In the final and authoritative codification of Jewish law as given in Josep Caro s sixteenth century Shulhan Aruch there is a section known as Yoreh De ah giving nine rules pertaining to gallbladder conditions A translation of these rules as made by Rabbi Louis Epstein of Boston was published by Boyden as an appendix to his article on accessory gallbladders (*Am J Anat* 38 218 1926) Too long to be published here a brief synoptic concept of the laws may be formulated in the following sentence If the gall bladder is perforated has been removed by hand is missing or is double or if hard things like the pits of olives are found in it then the animal is terefah i e unfit for food Thus according to Boyden s studies the double gallbladder has been depicted as far back as the middle of the ninth century while the anatomy of the liver according to Jastrow had its beginning 3000 B C in the divination rites performed by the Babylonians on the liver of a sacrificial sheep

Remnants of the association of the liver with courage and the spirit of a red blooded fighting individual are to be

found in Shakespeare s *Henry IV*, Part 2 where Falstaff says

The second property of excellent sherris is the warming of the blood which before cold and settled left the liver white and pale which is the badge of pusillanimity and cowardice

Up to 1628 when Harvey discovered the circulation of the blood the liver was associated with a spirit or pneuma In the second century A D according to Cobb Galen put forth the theory that the basic principle of life was but a part of the general world spirit that was drawn into the human body through the act of respiration entering the blood through the lungs Since the liver formed the blood it imparted to it an essential natural spirit or pneuma After receiving the natural spirit from the liver, the blood acquired a second pneuma the vital spirit in the heart From here some blood was brought to the brain where it acquired a third pneuma the animal spirit which was distributed by nerves then thought to be hollow As currently conceived the first actual functional activity of the liver to be discovered was the formation and the storage of glycogen by Claude Bernard in 1848 Eleven other functions have since been discovered, but our knowledge of liver function is far from being completed, as instanced for example in the hepatorenal syndrome i e impairment of liver function producing a counter impairment of kidney function

History of the First Cholecystectomy in America by Justus Ohage (1886)

Through Dr F Schuldt (Univ of Minnesota surgeon at St Joseph s Hospital St Paul Minn and his family physician) the author was informed of an article written by Justus Ohage son of Justus Ohage Sr who performed the first cholecystectomy in America In view of the historical import of this achievement it is but appropriate to give a reprinting of the entire article for nowhere else is there to be found a report as interesting and as complete as this one is The James Marion Sims spoken of in this paper was a graduate of Jefferson Medical College three years after its foundation which was in 1825 Sims life story is admirably recorded in *A Woman s Surgeon* by Searle Harris (Macmillan Co 1950)

CHOLECYSTECTOMY ITS ORIGIN AND PRESENT STATUS*

JUSTUS OHAGE M D
Saint Paul Minnesota

This year 1946 marks the sixtieth anniversary of the first—and incidentally successful—cholecystectomy performed in the United States The operation was done in this city Saint Paul Minnesota at St Joseph s Hospital[8 11] The date was September 21 1886 I admit to a special interest in this operation and to the origins of cholecystectomy because the operator on this occasion was my father Justus Ohage assisted by Drs Nelson Schulin Dedolph Denny and Welsh also of this city

This year also marks the hundredth anniversary of the birth of the surgeon who performed the very first cholecystectomy

Today cholecystectomy is a common—one might almost say routine—operation It has been performed many thousands of times both in this country and abroad Yet a little more than sixty years ago it was a question whether it could or should be done at all It is interesting also to note that cholecystectomy has been a fairly stable operation Except for general improvements in operative technique especially with regard to asepsis we are doing it today in much the same fashion that it

* Presidential Address before the Ramsey County Medical Society Saint Paul Minnesota January 28 1946

was done by European and American surgeons who first attempted it

I shall take this occasion therefore to recall for contemporary as well as historical interest the origins of cholecystectomy While I do not pretend in any sense to be a historian of medicine I am persuaded to the practical and useful aspects of medical history The editors of the newly organized *Journal of the History of Medicine and Allied Sciences* have written aptly in an introductory editorial[10]

> The historical approach is invaluable in comprehending the nature of difficult problems We must have a knowledge not only of the actions of the past but of the mental struggles the philosophical conflicts that preceded action

From that approach I wish to review in some detail the early classical contributions to cholecystectomy and its forerunner cholecystotomy

Credit for performing the first successful removal of the gall bladder[4] goes to the surgeon Carl Johann August Langenbuch[6] the hundredth anniversary of whose birth occurs this year Langenbuch was born in Kiel Germany in 1846 After graduation from the University of Kiel in 1869 he went to Berlin where he began his career as an assistant in the Bethany Hospital From 1873 until his death in 1901 he was an important figure at the Lazarus Hospital He was a zealous worker in several fields and published much To his name is attached the research which eventuated in nerve stretching procedures in tabes He also worked extensively in the study of diseases of the liver and gall bladder his Surgery of the Liver and Gall Bladder was published in 1894 He was among the first who dared to resect a lobe of the liver He dealt also with hydatids of the liver and the treatment of seriously exposed large blood vessels with zinc chloride paste But we remember Langenbuch tonight as the first surgeon who successfully extirpated the gall bladder

I quote now from Langenbuch s discussion and description of this first successful case This paper in German appeared in the *Berliner Klinische Wochenschrift* in 1882 under the title A Case of Extirpation of the Gall Bladder in the Treatment of Chronic Gallstones Recovery[6] In passages that reflect the mental struggles the philosophic conflicts that precede action Langenbuch writes

> The surgery of the gall bladder is still in the infancy of its development but it does exist and the names of Petit Thudichum M Sims Kocher G Brown Lawson Tait Konig and others are in a general way associated with it Concerned with stone formation they have until now gone only so far as exposing the gall bladder freely and have been satisfied to widen fistulas and extract stones whenever hydrops or empyema of the gall bladder call for an operation They have busied themselves with the product of the disease not the disease itself

Langenbuch himself first became seriously interested in the problem in 1874 when he encountered a particular case of a forty year old man with insidious gall stones He was prompted to undertake a series of animal experiments which brought him to the conclusion that

> Of all abdominal operations to which laparotomy is the prelude extirpation of the gall bladder with preliminary ligature of the cystic duct appears among the least hazardous to attempt

In June 1882 shortly after the conclusion of his experiments Langenbuch was called into consultation by Dr N Meyer to see a forty three year old patient Mr D a magistrate secretary in Berlin who was suffering from acute gallstone disease Langenbuch reports his history thus

> He had endured his first mild attack in 1866 but recovered Thereafter attacks came more frequently and jaundice increased He had taken the cure at Carlsbad for three years without success The first year he had weighed 89 5 kilograms the next year 75 kilograms and now only 59 5 kilograms (1961/ pounds) For the last nine months the recurrent pain was so intense that he had to be maintained on increasing doses of morphine He was very depressed he constantly complained his strength was failing and without morphine he could not leave the house He had to give up his employment and his future indeed looked black

Langenbuch explained the risk and the possibilities of the projected operation cholecystectomy to the patient On July 10 1882 the patient entered the Lazarus Hospital and asked Langenbuch to undertake the operation The patient was kept in bed for five days during which time he suffered two acute exacerbations of pain

The operation was scheduled for July 15 1882 and did indeed take place on that day As demanded by the novelty of the case writes Langenbuch preparations

found in Shakespeare's *Henry IV*, Part 2 where Falstaff says

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* Presidential Address before the Ramsey County Medical Society Saint Paul Minnesota January 28 1946

pain itching nausea vomiting and in the production of stools natural in color and odor Unfortunately however the patient died eight days after the operation due to hemorrhage Sims considered the operation nevertheless a triumph for Listerism for postmortem examination proved that there was not the least trace of peritonitis or other untoward complication to be found as a direct result of the operation

In the course of the operation under ether anesthesia Sims amputated a portion of the gall bladder protruding through the incision Apparently it did not occur to Sims to remove the entire gall bladder Lacking Langenbuch s extensive studies he may have been extremely doubtful whether life was compatible with the absence of the gall bladder At any rate he states It will be better to incise the gall bladder rather than to remove any portion of it

I quote now a few pertinent statements from Sims paper again illustrating the mental struggles the philosophical conflicts that precede action in the direction of gall bladder surgery Sims wrote

> I believe the operation is unique Is it justifiable? I think it is because it is an imitation of the process adopted by nature in all cases in which recovery takes place Death is absolutely certain in every case where the gall ducts are mechanically obstructed unless an outlet be obtained either into the alimentary canal or by a fistulous opening externally through the abdominal wall But this case proves that it is not necessary to wait for the tedious efforts of nature Were I called on to operate again under similar circumstances I would not procrastinate it a day after the diagnosis was fully established For it is certain that the longer it is put off the more the blood becomes poisoned by the bile and the more the chances of recovery are diminished

It is too much the fashion nowadays wrote Sims in 1878 when Listerism was making possible operations that would have been considered absurd a few years previously to coin new names for old operations But this is a new operation and we must find a name for it Cholecystotomy (from the Greek gall bladder and incision) will answer He rightly predicted that cholecystotomy would open a great new field in the domain of abdominal surgery

The first successful case of cholecystotomy with recovery five weeks after operation was performed by Kocher in June 1878

Experience over more than sixty years has now demonstrated that cholecystectomy as introduced by Langenbuch rather than cholecystotomy devised by Sims is the more useful and probably the less hazardous operation though each has its place Very recent statistical studies appear to bear this out In a series of 332 cases of acute cholecystitis reviewed by B C Smith[13] in 1915 cholecystectomy was performed on 223 patients with a mortality rate of 3 5 per cent and cholecystotomy was performed on 103 patients with a mortality rate of 11 6 per cent In another series of 123 cases of acute cholecystitis reviewed in 1945 to determine the comparative value of early (that is within seventy two hours) and late operative intervention McGuigan[7] concludes that when delay results in improvement of the condition of the patient cholecystectomy is to be preferred to cholecystotomy and seems to be better borne than the less radical operation The average mortality in this series was 12 7 per cent for the early operations 2 38 per cent for the delayed operations

In 1946 then the year marking the sixtieth anniversary of the performance of the first cholecystectomy in the United States and the hundredth anniversary of the birth of the surgeon who first performed this operation we need conclude nothing more elaborate than to offer affirmative testimony that the earliest hopes as to the utility of this operation have been amply confirmed Would that all surgical hopes were as fully justified

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were made for carrying out the operation with all aseptic precautions At this point we may recall that the modern era of surgery introduced largely by Joseph Lister was still very young and the distinction was not altogether clear between antiseptic surgery employing carbolic acid dressings and spray and aseptic surgery emphasizing *the exclusion of contaminating agents by* the practice of absolute cleanliness Lister s famous paper On the Antiseptic Principle of the Practice of Surgery had appeared only fifteen years previously in 1867

With aseptic precautions as they were understood in 1882 then and with the assistance of Dr A Martin and Prof Dr F Busch as well as the presence of other guests Langenbuch began the first successful cholecystectomy He has described the operation and its results as follows

> The operation proceeded smoothly through a I incision The gall bladder was found to be massively full of gall and was emptied by aspiration with a *syringe Two chestnut size cholesterin gallstones* were found When the gall bladder was detached from the liver a small venous bleeding occurred This was controlled with a catgut stitch
>
> After the operation the patient felt no pain and slept well the following night Next day his pulse and temperature were normal he felt no pain and he smoked a cigar He left his bed on July 27 His old pain had not recurred up to mid November *He had gained 13 kilograms in weight and he no* longer needed morphine

At this time Langenbuch felt that he had answered the physiologic and technical questions concerning the feasibility of cholecystectomy in man He wrote Clinically I believe we should be alert to extirpation of the gall bladder with preliminary ligation of the cystic duct as the least dangerous and most hopeful method for the relief of many pathological processes arising in these organs Experience has justified his statement

Within four years after Langenbuch s first cholecystectomy the operation was performed nine times with eight recoveries a mortality rate of 11 per cent[9] The operation in this city the first in the United States was the ninth in the world Five were performed by Prof Langenbuch with one death two by M Thiriar both successfully one successfully by Courvoisier

Obviously however cholecystectomy was not the only *surgical procedure entertained* for relief of diseases of the gall bladder Its immediate predecessor was cholecystotomy Credit for the first cholecystotomy for the removal of gallstones[4] has been assigned to an American physician John Stough Bobb (1809–1870) who reported a case of lithotomy of the gall bladder in the Transactions of the Medical Society of Indiana *for 1868 The operation of lithotomy for* the removal of gallstones had been proposed in the 18th century by the French surgeon Jean Louis Petit[1] (1674–1750) who lectured on surgery at Paris and devised many operations He suggested that if the gall bladder was dilated and adherent to the abdominal wall it might be punctured and stones extracted with a long forceps Similarly fistula might be dilated for this purpose Vogel a surgeon of Lubeck is said to have performed this operation in the 18th century and considered it one of the very finest surgical operations Borrichus[1] in the 17th century observing many *fatal* cases of *dropsy of the gall* bladder from impacted gallstones had among others raised the question of surgical interference Far earlier in antiquity Hippocrates and Galen gave descriptions of gallstones and diseases dependent on them

However the classical description of cholecystotomy and in fact the invention of this name for the operation itself is ascribed to James Marion Sims Sims was an American, born in *1813* in *South Carolina* He practiced in Alabama and New York Sims was one of the early presidents of the American Medical Association (1876) He later moved to Europe where he was made an honorary fellow of the obstetrical societies of London Dublin and Berlin He died in 1883 His classical Remarks on Cholecystotomy in Dropsy of the Gall Bladder[1] were published in the *British Medical Journal* in 1878

In this paper Sims reports the case of an American woman aged forty five a resident of Paris on whom he performed the operation of cholecystotomy The date was April 18 1878 This patient had all the symptoms of acute mechanical obstruction of the gall bladder She is described as being mahogany colored with jaundice The benefit of the operation Sims reported was shown by immediate relief of

pain itching nausea vomiting and in the production of stools natural in color and odor Unfortunately however the patient died eight days after the operation due to hemorrhage Sims considered the operation nevertheless a triumph for Listerism for postmortem examination proved that there was not the least trace of peritonitis or other untoward complication to be found as a direct result of the operation

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An extensive account of the life history of Dr Justus Ohage was published by Justus G Schifferes B A, M A in 1930 (The Adventurer Surgeon in *Journal Lancet* 51 96 1931) In order that all surgeons may readily become acquainted with the history of Ohage the following excerpts from Schifferes article, with a few additions thereto are presented

Justus Ohage was born in Hanover Germany October 13 1849 son of a physician Dr Georg Ohage After attending the Gymnasium and the Lyceum of that city he came to America where he fought in the Civil War Wounded therein he was hospitalized at City Point Virginia in April 1865 at a time when Lee had just surrendered at Appomattox When President Lincoln on a visit to the hospital learned that Ohage was the youngest wounded soldier of the Army of the Potomac he came to his cot shook hands with him and commended him for his bravery A soldier companion of Ohage Sergeant Lippincott of the 8th Regiment of New Jersey fostered in him a love of outdoor adventures as woodsman fisherman and hunter These experiences Ohage later recorded in a book entitled *Sixty Years with Rod and Gun*, which was printed privately

Before choosing medicine as a career Ohage worked as a medical assistant in a construction crew of the Topeka Atchison Railroad and spent some time as a hunter in the Missouri Bottoms When 27 years of age he met Dr Sidney Ensor, a graduate of Guy s Hospital and Thomas s Hospital London After marrying his daughter Augusta he attended the medical school of the University of Missouri, in Columbia from which he received his medical degree (M D) in 1880 Immediately after graduation he went to Europe where he began his postgraduate medical studies with special emphasis on surgery at the Universities of Gottingen and Kiel These studies were continued at Berlin where he came under the tutelage of the pathologist von Virchow and the eminent surgeon Bernard von Langenbuch who performed the first cholecystectomy successfully on July 15 1882 Later he went to London for training at Guy s and Thomas s Hospitals and finally ended his postgraduate studies at Edinburgh being trained there in abdominal surgery by Keyes

After completing his internship in the Henriettenstift Hannover Ohage returned to America and in 1881 set up his practice of medicine in St Paul Minnesota One of his best friends was Dr William Worrell Mayo of Rochester who thought so highly of Ohage as a surgeon that he repeatedly sent his sons William and Charles to St Paul to watch him operate

On September 24 1886 Ohage performed the first cholecystectomy in America (ninth in the world) at St Joseph s Hospital (third floor of the east wing) in St Paul Minnesota the patient being Mrs Lena A Swede 35 years of age This highly successful case was reported in the *Northwestern Lancet* (6 551 November 1886) Because of his accomplishment in surgery Ohage was elected President of the Ramsey County Medical Association in 1889 and 1890 and President of the Minnesota State Medical Society in 1895 In 0 he

was appointed Clinical Professor of Surgery at the University of Minnesota a position he held until 1899 For many years (1892–97) he was a member of the State Board of Medical Examiners and in recognition of his work was elected to the Imperial Surgical Society of Berlin

At the height of his surgical career 1899 to the amazement of his colleagues and associates Ohage decided to become Health Commissioner of the city of St Paul a position which he held until 1917 In this new field of endeavors he was highly successful being among the first in America to establish laws and ordinances regarding pure foods the filing of birth and death certificates compulsory vaccination in public schools milk inspection garbage and sewage disposal sanitation in public baths and various other medical measures for the betterment of public health So effective were his ordinances carried out that at the St Louis World s Fair in 1904 Ohage was awarded a medal for having made St Paul one of the most healthful cities in the world He died in his beloved city of St Paul December 26 1935 Dr E Starr Judd mentions the history of Ohage s surgery in Dean Lewis s *System of Surgery*

Interesting from a historical point of view is the following account of the first cholecystectomy in America performed by Ohage as he recorded it in the *Medical News* 50 202–206 232–236 February 19 and 26 1887

As soon as the abdominal cavity was opened the tumor presented itself which proved to be an enormously distended gall bladder with exceedingly thin walls After pushing the bowels aside and getting my hand under the liver I detected a large stone firmly impacted in the cystic duct completely obstructing it All the gentlemen assisting me followed my example and each felt the stone plainly The walls of the gall bladder were so exceedingly thin that the greatest delicacy was necessary in handling it Yet unopened as it was it promised such a good hold in handling it while detaching it from the liver that I did not now aspirate it as Langenbuch does but first separated it completely from all sides After this was done by careful manipulation I succeeded in working the obstructing stone from the cystic duct back into the gall bladder All ducts were now closely examined They were free and unobstructed I now ligated the cystic duct with carbolized silk and punctured the base of the gall bladder with the point of a knife evacuating more than a pint of a transparent muco-serous liquid and a few small stones the gall bladder being meanwhile held outside of the abdomen After it was emptied of its liquid contents I divided it close to the ligature with the Paquelin cautery and removed it with all the stones it contained 135 in number The ligature was cut short and the stump after being dusted with iodoform dropped A few layers of Lister gauze which had been stuffed into the abdominal wound to catch up any liquid that might escape were removed and after washing that part of the bowels and liver which had been exposed with a 1 2000 corrosive sublimate solution the whole wound was closed with deep and superficial silk sutures iodoform freely dusted over it and a large pad of absorbent cotton applied and held *in situ* by a binder tightly secured No drainage tube was put in

The patient reacted well There was scarcely any shock and aside from the usual ether vomiting which was controlled by hypodermatic injections of morphia and cracked ice by the mouth she was in every way comfortable There is nothing of special interest in her convalescence On the eighth day I removed the dressing for the first time and finding the whole wound healed by first intention removed all sutures and simply supported the abdomen with a binder She sat up on the eleventh and went out on the thirteenth day after the operation Her appetite is good she is free from all pain and has in every way fully recovered

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was begun only after completion of the sketched drawings thereby avoiding preconceived notions as to classification of patterns and ascertainments of percentages The text of this atlas is based on a synthesis of arterial data listed under 35 different headings on a single chart the latter presenting a common meeting ground from which conclusions were drawn Of the 200 specimens statistically estimated 181 were males (117 white 61 colored) and 19 were females (13 white 6 colored) Ages varied from 25 to 90 years the vast majority being over 50 years of age

All told over 500 bodies were dissected personally by the author in this investigation of the blood supply of the upper abdominal organs—100 on the splenic artery 100 on the celiac axis alone 200 statistically analyzed as regards origin and distribution of all arteries to the supramesocolic organs and 100 on which only those arterial variations which were strikingly different and unusual have been recorded To these may be added the 150 plastic corrosion casts of human livers made by Healey and Schroy of the Daniel Baugh Institute of Anatomy from which the knowledge of the intrahepatic distribution of hepatic arteries and bile ducts and their terminology was obtained—a total therefore of 650 bodies

Terminology

There is considerable confusion in the literature as regards the nomenclature of the arteries emanating from the celiac axis and the upper segment of the superior mesenteric This confusion is due to the fact that the variational anatomy of the celiac artery is so extensive that in an investigation of 200 bodies only about one half of the samples will conform to the standard textbook description It is obvious that with this wide margin for selection any classification of the celiac axis into specific types or groups is purely arbitrary as there are many cases in which doubt exists as to which type or group an artery belongs The main cause for the aberrant morphology of the celiac axis is the frequency and the diversity of origin and distribution of the hepatic arteries The latter may arise not only from the celiac trunk but also from the aorta the left gastric or the superior mesenteric It is suggested that the term celiac trunk be used to express a stem which typically gives rise to the left gastric the splenic and the hepatic arteries the latter dividing into its three main branches (right left and middle hepatic) Such a celiac trunk is complete and is synonymous with the term hepatolienogastric trunk The celiac trunk (celiac artery) very frequently is incomplete due to its failure to give off one of its characteristic branches It may omit the left gastric forming a hepatolienal trunk or the hepatic forming a lienogastric trunk or the splenic forming a hepatogastric trunk Incompleteness of the celiac trunk is obtained further by the shifting of one or more of its branches (the left gastric may arise from the aorta the hepatic or the splenic the hepatic from the aorta the left gastric the splenic or the superior mesenteric the splenic from the aorta the hepatic the left gastric or the superior mesenteric) Finally incompleteness may be obtained by reallocation of one of the three branches of the hepatic (right middle or left hepatic)

The main variations of an incomplete celiac comprise the following patterns (1) the right hepatic arises from the superior mesenteric (hepatomesenteric trunk) leaving only a celiacal left hepatic (Fig 84) (2) the left hepatic arises from the left gastric leaving only a celiacal right hepatic (Fig 76) (3) the right hepatic arises from the superior mesenteric (hepatomesenteric trunk) the left hepatic from the left gastric leaving only a middle celiacal hepatic

Not from books but from dissections not from the tenets of philosophers but from the structure of Nature do I profess to learn and to teach Anatomy

—WILLIAM HARVEY, in his immortal lecture to the Royal College of Physicians London 1628

4

Material, Methods and Terminology

This descriptive atlas completed and published 327 years after William Harvey made the above statement is a natural sequel to the author s investigations of the variational anatomy of the spleen and the splenic artery made from 1936 to 1940 on 100 bodies in the anatomic laboratories of Jefferson Medical College and reported in the *American Journal of Anatomy* in 1942 While dissecting the celiac axis in these cases the author noted the amazing variation in its configuration and in the origin and the distribution of the hepatic arteries Thereupon the author decided to investigate *the variational anatomy of the* celiac axis itself but after dissecting over *100* new samples (never published) he realized that a study of the celiacal branches alone was insufficient and inaccurate for a celiacal hepatic in its ultimate distribution often was only the right or the left hepatic—a so called accessory left hepatic from the left gastric was often not an accessory but a replaced left hepatic and an accessory right hepatic from the superior mesenteric was more frequently a replaced right hepatic than an accessory

To avoid possibility of confusion and error as regards the celiac complex and the upper segment of the superior mesenteric artery for a period of 6 years the author dissected in 200 bodies of the anatomic laboratory the entire arterial blood supply of the supramesocolic organs To this effect the arteries supplying the liver the gallbladder the stomach the duodenum the pancreas and the spleen were painstakingly dissected from their origin to their ultimate distribution in the substance of the respective organs Seriation of the bodies was fairly sequential only those bodies being rejected in which the arteries were not well injected with a carmine starch solution or which showed marked pathologic changes

In every instance dissection of the regional arteries and sketches of them were *made previous to their manipulation* study and dissection by students for long experience *has shown that* arteries once tampered with by first year students are as a rule rendered questionable as to origin and distribution The finer details of terminal ramifications and endings of the regional arteries especially of the cystic and the hepatic were worked out personally by the author in excised specimens these comprising in every instance *en bloc* all of the supramesocolic organs Only after the author had completed pencil sketches of the entire arterial bed were the artists (7 all told) with specimens before him or her given the task of redrawing the author s sketches for publication The statistical study of the arterial variations in the 200 bodies investigated

51, 95, 97) and the caudate lobes (Fig. 57).

When a hepatic artery arises from a source other than the terminal end of the celiacal trunk, it is considered an aberrant hepatic. There are two kinds of aberrant hepatics: accessory and replaced. The term accessory hepatic should be used only in those cases where the normal celiacal right or left hepatic is present. The term accessory then has its exact meaning—i.e., there is an extra right or left hepatic present from other sources, the "extra" to be interpreted only from the viewpoint of origin, for functionally considered, all hepatic arteries are essential, as proved in the plastic casts made by Healey and Schroy (1952).

When the normal celiacal right hepatic is missing, the artery supplying the right lobe comes from another source—in most instances independently from the aorta (Fig. 66) or from the superior mesenteric (Fig. 82). Such a right hepatic is termed a replaced right hepatic. Similarly, when the normal celiacal left hepatic is missing, the artery supplying the left lobe is replaced (replaced left hepatic) from another source, either from the celiacal left gastric (Fig. 76) or from the aorta or the superior mesenteric via a common hepatic trunk (Fig. 53). In view of the adopted terminology, a body may have more than one replaced hepatic and, similarly, more than one accessory hepatic. Again, a body may have a replaced right hepatic with an accessory left hepatic, or, vice versa, an accessory right hepatic with a replaced left hepatic. Details of the possible combinations will be considered when samples are discussed. The point to be emphasized here is a relatively simple one, viz., that only a right or a left hepatic co-existing with a normal celiacal right or left hepatic is to be termed an accessory and only when the normal right or left celiacal hepatic is missing is the replacing vessel (coming from another source) to be termed a replaced right or a replaced left hepatic.

Since the middle hepatic is usually a branch of either the right or the left hepatic, the item (whether it is a normal celiacal branch or whether it is a replaced middle hepatic) will depend on the nature of the hepatic from which it arises. While there are a few cases having a distinct celiacal accessory middle hepatic, in the majority of bodies accessory middle hepatics to the quadrate lobe arise as branches of the right or the left hepatic.

According to Healey and Schroy, the middle hepatic (medial segment artery) is always a branch of the left hepatic, but their terminology of what constitutes the left hepatic artery is based on casts of excised autopsy livers, whereas the beginning of the left hepatic artery frequently takes place far extrahepatically, and the middle hepatic artery (medial segment artery) takes orgin from the right hepatic long after the latter has parted company with the left hepatic artery.

As regards the nomenclature of other regional arteries, the term supraduodenal will be used in the sense originally proposed by Wilkie, viz., as designating the artery of varied origin (from the hepatic or its branches, from the gastroduodenal or the right gastric) supplying the upper border, the anterior and the posterior surfaces of the first part of the duodenum. The term retroduodenal originally was employed by Wilkie to designate a small arterial branch of the gastroduodenal to the posterior wall of the first and sometimes of the second part of the duodenum.

In this atlas the term retroduodenal is used to designate the artery which forms an arcade on the entire posterior wall of the duodenum and the head of the pancreas and which, as a rule, is the

(Fig 55) (4) the celiacal hepatic is missing i e the entire hepatic arises from the superior mesenteric (hepato mesenteric trunk) leaving only a gastro lienal trunk (Fig 53) (5) the left gastric arises separately from the aorta leaving a hepatolienal celiac trunk (Fig 69) (6) the left gastric the lienal and the left hepatic form a common celiac trunk (hepatogastrolienal) the right hepatic arises separately from the aorta (Fig 66) (7) the hepatic the lienal and the superior mesenteric form a common trunk from the aorta (the hepatolieno mesenteric) the left gastric arising separately from the aorta (Fig 56) (8) finally all of the four arteries (left gastric lienal hepatic and superior mesenteric) form a common trunk (celiaco mesenteric) Many odd patterns occur (Figs 64 67)

Just as the celiacal trunk (celiac artery) may be incomplete so in very many instances it has supernumerary branches (1) the right or the left inferior phrenic or both (2) an accessory right or left hepatic an accessory left gastric an accessory inferior phrenic (3) the dorsal pancreatic (Fig 80) (4) *the middle or the left colic or the accessory middle colic* (Fig 40) (5) the gastro duodenal the retroduodenal or the supraduodenal (Fig 55)

Hepatic Arteries In reading the literature one is impressed with the looseness and the nonuniformity of meaning with which the term accessory hepatic has been used Many authors failed to state whether the accessory hepatic is really an accessory or whether it is a replaced type of hepatic To clarify this situation the following method of nomenclature of hepatic arteries is adopted A typical normal hepatic artery arises from the celiac trunk and divides into three main branches the right hepatic entering the right lobe a left hepatic entering the left lobe and a middle hepatic entering the quadrate lobe

The middle hepatic as observable in the author s dissections is usually a branch of the right hepatic (45 per cent Fig 52) or the left hepatic (45 per cent Fig 49) and in 10 per cent is derived from other sources as the celiac the gastroduodenal the hepatic or the right gastric In some instances it is the only celiac hepatic present as illustrated in Figure 67 In texts of anatomy (with the exception of the new 11th edition of Morris by Schaeffer 1953) it is not described or illustrated but in view of the fact that it often gives off the superficial cystic and in instances is the only celiacal hepatic present it obviously should be included in all texts of anatomy and surgery especially since the middle hepatic branch of the hepatic artery was known since the times of Haller (1756) and of Tiedemann (1822) as the arteria hepatica media (the ramus medius of Adachi 1928) Healey and Schroy designated the artery as the medial segment artery for in the 150 plastic corrosion casts they made at the Daniel Baugh Institute of Anatomy the middle hepatic (medial segment artery) supplied the medial segment of the left lobe of the liver This segment comprises in extent not only what has been known as the quadrate lobe but also that part of its extension to the parietal surface under the diaphragm where no anatomic markings of its limits are discernible

It should always be borne in mind however that no hepatic artery is entirely restricted to the region it predominantly supplies Thus the right hepatic often supplies the caudate lobe via a long branch which courses under the portal vein to end in the papillary process (Fig 69) The middle hepatic may send branches to the left lobe (Fig 60) and vice versa the left hepatic may send branches to the quadrate (Figs

One of the chief fascinations of surgery is the management of wounded vessels the avoidance of hemorrhage The only weapon with which the unconscious patient can immediately retaliate upon the incompetent surgeon is hemorrhage If he bleeds to death it may be presumed that the surgeon is to blame whereas if he dies of infection or shock or from an unphysiological operative performance the surgeon s incompetence may not be so evident

—WILLIAM STEWART HALSTED

5

Observations on the Blood Supply of the Liver and the Gallbladder (200 Dissections)

Types of Celiac Axis

As previously stated constituents of the celiac axis and the upper segment of the superior mesentery vary to such an extent that any classification of the axis is purely arbitrary and accordingly will differ with the viewpoint adopted by the author and the thoroughness with which the samples were investigated After a careful analysis of the variational patterns observed in the 200 bodies investigated and listed for statistical estimate they are categorized in the following types

Type I Hepatolienogastric Trunk This type of celiac trunk has the left gastric the lienal and a hepatic artery—either the common hepatic (Fig 49) or its right or left branch (Figs 57 84) It occurred in 89 per cent of the bodies leaving a total of 11 per cent for all other types observed In 129 cases (64 5 per cent) the hepatolienogastric trunk was complete i e contained the full hepatic with its right left and middle hepatic branches plus the left gastric and the lienal In many cases it had a supernumerary branch i e in addition to its three typical branches it gave rise to the dorsal pancreatic (Fig 82) or a colic branch (middle left or accessory colic Fig 10) In 23 bodies (11 5 per cent) in addition to a celiacal hepatolienogastric trunk there was a hepatomesenteric trunk—i e some of the hepatic blood supply came from the superior mesenteric (Fig 86)

As a rule the left gastric is the first branch of a hepatolienogastric trunk (Fig 91) In this it differs from the hepatic which very rarely is given off as the first branch The point of origin of the left gastric from the hepatolienogastric trunk varied considerably anywhere from the latter s aortic origin to its distal end The tripod of Haller in which the left gastric the hepatic and the splenic take origin from a common point occurred in 25 per cent (Fig 89) In 5 per cent a fourth artery usually the dorsal pancreatic arose from a common point thus forming a tetrapod type of celiac trunk (Fig 80) Of the three branches the left gastric is the smallest in caliber (4 to 5 mm) The splenic (7 to 12 mm) and the hepatic (6 to 10 mm) vary the splenic often being larger than the hepatic

Type II Hepatolienal Trunk In this type (3 5 per cent) the hepatic and the lienal arise from a common celiac trunk (Fig 69) The left gastric is displaced

first branch of the gastroduodenal (Figs 56 71) It is synonymous with the term posterior superior pancreaticoduodenal (Petren Pierson Woodburne and Olsen) to distinguish it from the anterior superior pancreaticoduodenal The latter artery is described and illustrated in texts of anatomy the former with few exceptions (Morris Grant) is not The textually unlisted artery supplying the posterior surface of the pancreas in the neck region (Fig 82) (where the head joins the body) is termed the *dorsal pancreatic (superior pancreatic of* Petren, Pierson) Finally, the artery coursing along the inferior surface of the pancreas at the tail of which it unites with a branch of the splenic (Fig 50) is termed the transverse pancreatic artery as first employed by Haller in 1761 (inferior pancreatic of Testut Petren Pierson Woodburne and Olsen)

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Before beginning the next chapter and presenting the vast array of seemingly baffling anatomic data on the presence of anomalous arteries and bile ducts in the gallbladder region (with which every biliary surgeon should be familiar at least to the extent portrayed in this atlas) and as an unsought for but gratifying justification for publishing this part of the blood supply of the upper abdominal organs more extensively than any other author the following excerpts from an article by one of America s most brilliant biliary surgeons the late Dr Lahey of the Lahey Clinic in Boston as written with his associate Pyrtek and substantiated with vast experiences by Cattel are given

After an experience in the operative management of 280 patients for stricture or destruction of the *bile ducts* Lahey and Pyrtek begin their article by stating

It is unfortunate that when the accident of a bile duct injury occurs it is often in a patient who is otherwise well usually not too advanced in years and were it not for the duct injury would have the same prospect of length of life and good health as would a normal well person

It is to be remembered that each time a cholecystectomy is done there is a real danger of injury to the bile ducts or hepatic artery with the consequent possibility of producing in the patient concerned invalidism shortening of life or an operative fatality

As an anatomist with nearly 20 years of experience in studying the variational anatomy of the hepatic pedicle the author advises every prospective *surgeon* to read this article by Lahey and Pyrtek for it is replete with information and illustrations regarding the hazards met with in cholecystectomy the proper methods of removing the gallbladder and successfully assayed technics in the repair of cut hepatic ducts

TABLE 5 MEASUREMENTS OF THE LENGTH AND THE WIDTH OF 50 CELIAC TRUNKS

Length in mm	8-16	17-25	26-30	31-40
Times	6	26	12	6
Width in mm	7-9	10-12	13-20	Varied caliber
Times	9	31	6	4

TABLE 6 DISTANCE BETWEEN THE ORIGIN OF THE CELIAC TRUNK AND THE SUPERIOR MESENTERIC

Distance in mm	1-3	4-6	7-9	10-12	13-15	22
Times	15	15	7	3	6	1

pancreatic which was anastomosed with the inferior mesenteric

As seen from the samples measured the interval on the aorta between the origin of the celiac trunk and the superior mesenteric shows considerable variations (from 1 to 22 mm) it most commonly being 1 to 6 mm (60 per cent) Occasionally the interval is the site of origin of the inferior phrenics (Fig 87)

Succinctly summarized the superior *mesenteric may incorporate the celiac* axis completely thereby constituting a celiacomesenteric trunk it may miss the left gastric thus forming a hepatolienomesenteric trunk it may incorporate a hepatic forming a hepatomesenteric trunk or the splenic forming a lienomesenteric trunk

Just as the celiac trunk may be constricted at its point of origin from the aorta by pressure of the diaphragmatic crura so the superior mesenteric at its origin from the aorta may show constrictions deep or shallow spiral like indentations (at times a centimeter or more long) the causative factor for which is embryologic They are vestigial effects of the primitive gut rotation which takes place about the superior mesenteric artery (270) the artery itself making a 180 rotation

Basic Types of the Hepatic Arterial Blood Supply

The complexity and the varied character of the arterial blood supply to the liver and the gallbladder are due primarily to the varied sites of origin of the three major liver arteries viz the right the left and the middle hepatics the latter supplying the quadrate lobe secondarily to the mode of the terminal extrahepatic branching of these three major liver arteries An analysis of 200 cases shows that any sample of the hepatic arterial blood supply may with minor modifications be placed into one of the *following 10 basic types as illustrated* in the schematic sketches (Figs 8 and 9) and drawings (Figs 10–20) When present the celiacal hepatic supplies the following branches

Type I The right the left and the middle hepatics—textbook type and present only in about half of the subjects (55 per cent Fig 10)

Type II The right and the middle hepatics—the right hepatic replaced from the left gastric (10 per cent Fig 11)

Type III The left and the middle hepatics—the right hepatic replaced from the superior mesenteric (11 per cent Fig 12)

Type IV Only the middle hepatic—the right hepatic replaced from the celiac or the superior mesenteric the left hepatic replaced from the left gastric (1 per cent Figs 13 55)

i e arises separately from the aorta (Fig 69) the splenic (Fig 50) or the hepatic (Fig 54) It may be accompanied by a hepatomesenteric or a hepatogastric trunk in which cases part of the hepatic blood supply is diverted through these channels

Type III Hepatolienomesenteric Trunk In this very odd type of trunk (0 5 per cent) the sole celiac component *remaining in situ is the left gastric* which arises separately from the aorta The hepatic the lienal and the superior mesenteric arise from a common trunk derived from the aorta (Fig 56)

Type IV Hepatogastric Trunk In this type (1 5 per cent) the left gastric and the hepatic arise from a common trunk at the celiac site and the lienal *arises from the superior mesenteric the* two forming a lienomesenteric trunk (Fig 67) If the latter gives off a hepatic it is modified into a hepatolienomesenteric trunk (Fig 67)

Type V Lienogastric Trunk In this type of celiac trunk (5 5 per cent) the lienal and the left gastric arise from a common trunk and the hepatic artery is replaced from another source (Fig 66) *The hepatic may arise separately* from the aorta (2 per cent) (Fig 66) or take its origin from the superior mesenteric in which case there is no celiacal hepatic present *at all* (2 5 per cent) (Figs 38 53) A lienogastric trunk may give rise to the gastroduodenal the latter being displaced from the hepatic It may also give rise to an aberrant left hepatic

Type VI Celiacomesenteric Trunk As implied by the term the four regional arteries (hepatic left gastric splenic and superior mesenteric) arise from the aorta by a common trunk It apparently occurs very rarely for in this study of over 500 bodies the author found but two instances of it none having been observed in the 200 bodies estimated *statistically In many instances sites of* origin of the celiac trunk and of the superior mesenteric from the aorta were *very closely placed being practically* contiguous Such samples simulated a celiacomesenteric trunk yet when the aortic wall was slit posteriorly two openings instead of one were found on the anterior wall proving how readily two closely placed trunks could be mistaken for one

Type VII Celiacocolic Trunk In this *type the middle colic (two cases) or the* left colic (one case) takes origin from the celiac instead of from the superior mesenteric (Fig 40) The celiacal colic branch is nothing more than an enlarged (4 mm) dorsal pancreatic with which it was statistically estimated These celiacal colic trunks represent instances in which the dorsal pancreatic artery not only *supplies the pancreas but also continues* on below the pancreas as one of the main channels for the blood supply of the large intestine In some instances, the celiacal dorsal pancreatic functions as an accessory middle colic (Fig 41) It is important to know that it may anastomose with the superior mesenteric with the middle colic and even with the inferior mesenteric

Measurements of the Celiac Trunk Variations in the configuration of the celiac axis are accompanied by variations in the length and the width of the celiac trunk *In a study of 50 celiac trunks the* length of the celiac varied from 8 to 40 mm its width from 7 to 20 mm In many instances the caliber of the celiac is not uniform the diameter of the trunk at its origin from the aorta being considerably smaller (5 mm) than at its middle or distal points (10 mm) (Fig 48) The diminished caliber of the celiac trunk at its point of origin is due to the proximity and the constrictive action of the crura of the diaphragm In one instance the celiac was found to be occluded throughout most of its extent the blood supply in this case coming primarily from an enlarged dorsal

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pancreatic which was anastomosed with the inferior mesenteric

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Basic Types of the Hepatic Arterial Blood Supply

The complexity and the varied character of the arterial blood supply to the liver and the gallbladder are due primarily to the varied sites of origin of the three major liver arteries viz the right the left and the middle hepatics the latter supplying the quadrate lobe secondarily to the mode of the terminal extrahepatic branching of these three major liver arteries An analysis of 200 cases shows that any sample of the hepatic arterial blood supply may with minor modifications be placed into one of the following 10 basic types as illustrated in the schematic sketches (Figs 8 and 9) and drawings (Figs 10-20) When present the celiacal hepatic supplies the following branches

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Type II The right and the middle hepatics—the right hepatic replaced from the left gastric (10 per cent Fig 11)

Type III The left and the middle hepatics—the right hepatic replaced from the superior mesenteric (11 per cent Fig 12)

Type IV Only the middle hepatic—the right hepatic replaced from the celiac or the superior mesenteric the left hepatic replaced from the left gastric (1 per cent Figs 13 55)

Type V — The right the middle and the left hepatics—the left hepatic is double one being an accessory left hepatic from the left gastric (8 per cent Fig 14)

Type VI — The right the middle and the left hepatics—the right hepatic is double one being an accessory right hepatic from the superior mesenteric etc (7 per cent Fig 15)

Type VII — The right the left and the middle hepatics—in addition there is an accessory right hepatic from the superior mesenteric and an accessory left hepatic from the left gastric (1 per cent Figs 16 86)

Type VIII — Combination patterns of (a) a replaced right hepatic and an accessory left hepatic (Fig 17) or (b) an accessory right hepatic with a replaced left hepatic (2 per cent Fig 18)

Type IX — When the celiacal hepatic is absent the entire hepatic trunk is derived from the superior mesenteric (4 5 per cent Figs 19 38 53)

Type X — When the celiacal hepatic is absent the entire hepatic trunk is derived from the left gastric (1 case Fig 20)

The celiacal hepatic supplying the hepatic in most instances came from a hepatolienogastric trunk (89 per cent) Variations comprise a celiacal hepatic derived from modified trunks such as hepatolienal hepatolienomesenteric hepatolienal plus hepatogastric Sources of origin of aberrant right hepatics other than the superior mesenteric are the gastroduodenal the retroduodenal the dorsal pancreatic and the celiac for aberrant left hepatics other than the left gastric they are the superior mesenteric or the aorta

The mode of the developmental potential underlying the formation of the 10 basic types is as follows typically the hepatic after giving off the gastroduodenal divides into the right the middle and the left hepatics the middle hepatic (for the quadrate lobe) being a branch of either the right or the left hepatic (Figs 71 72) When the hepatic divides into the gastroduodenal and the right hepatic (latter with the middle hepatic) the left gastric is replaced by an artery from the left gastric (Fig 76) When the hepatic divides into the gastroduodenal and the left hepatic (latter with the middle hepatic) the right hepatic is replaced by an artery from the superior mesenteric (Fig 82) When the hepatic divides into the gastroduodenal and the middle hepatic both the right and the left hepatics are replaced (Fig 55)

Such replacing hepatics should henceforth not be called accessory right or left hepatics since functionally they are definitely not accessory but the only main right or left hepatics present (i e they are replaced hepatics) An accessory hepatic from the left gastric or from the superior mesenteric occurs only in conjunction with a typical left or right celiacal hepatic Such a hepatic is accessory however only in origin for functionally considered it too is indispensable in the blood supply of the liver as demonstrable in the plastic corrosion casts of Healey and Schroy where it is plainly visible that an accessory hepatic artery has a selective distribution to a definite region of the liver even as Clauser of the University of Pennsylvania (1953) has shown to be the case for every extrahepatic small branch of the hepatic artery by means of roentgenograms in work under Batson and Ravdin

In some instances the blood supply to the liver comes from three different sources, there being five hepatic arteries (three from the celiac hepatic, one from the superior mesenteric and one from the left gastric) (Figs. 16, 86). Healey (1953), after encountering such a case by dissection, followed the intrahepatic distribution of these hepatic arteries in a corrosion plastic cast and noted that each of the differently derived hepatic arteries had a specific distribution in the liver, none being accessory in its area of vascularization.

Terminal Arterial Vascularization of the Liver

Patterns of the terminal arterial blood supply to the liver are so markedly varied that, as in the case of the spleen, no two arterial patterns are the same. Not only does the hepatic artery show variations in the origin, the number, the caliber and the distribution of its branches, but much more so than in the spleen recourse is had to accessory arteries to augment the arterial blood supply. For the most part, the accessory hepatics come from the superior mesenteric and the left gastric.

A typical hepatic artery arises from the celiac trunk and, near the porta hepatis, gives off three main branches, viz., the right, the left and the middle hepatics (Fig. 71). Such a celiacal hepatic, however, occurs only in about one half of the subjects (55 per cent). In the remaining population, the right or the left hepatic is replaced from other sources. When the hepatic branches of celiac origin are small, the blood supply is augmented by accessory hepatics, right or left, as the case may be. Both of these points are discussed under the caption Aberrant Hepatic Arteries.

After its origin from the celiac trunk, the typical hepatic artery at first takes an irregular horizontal course from left to right along the upper border of the head of the pancreas and, sometimes, behind it to the pylorus or the first part of the duodenum, behind which it gives off the gastroduodenal, then ascends as the vertical portion. The hepatic is covered by peritoneum of the posterior wall of the omental bursa up to the right boundary of the isthmus of the bursa omentalis, where it passes forward in the right hepatopancreatic fold to enter the hepatoduodenal ligament, by which it reaches the porta hepatis, the common bile duct to its left, the portal vein behind it. In its ascent between the two layers of the lesser omentum, the hepatic lies in front of the foramen of Winslow, *a point to be remembered when compression of the artery is suddenly needed.*

In most subjects, the hepatic artery and its major three branches lie anterior to the portal vein and its tributaries. Exceptions are instances in which the right hepatic or one of its branches passes dorsal to the portal vein, this being always the case when the right hepatic arises from the celiac artery independently of the left hepatic (Fig. 54). The vertical portion of the hepatic lies, for the most part, entirely to the left of the common bile duct. Exact arterial relations to the latter and to the hepatic duct will be discussed later when the cystic duct is considered. For the present, it may be stated that in the majority of cases (85 per cent, 200 bodies) the right hepatic crosses the hepatic duct posteriorly (Fig. 72). In 15 per cent the right hepatic or one of its branches crosses the bile tract anteriorly (Fig. 70). When the right hepatic is double (3 per cent), one branch may cross anteriorly, the other posteriorly, or both branches may cross anteriorly or posteriorly (Figs. 61, 91).

As shown by Healey and Schroy (1953) and as illustrated in this atlas, the dual right hepatics owe their presence to the fact that the right hepatic divides extrahepatically into its anterior

and posterior segmental branches of the right lobe either to the right or to the left of the hepatic duct

Size of Hepatic Artery Despite the fact that the liver is from 5 to 6 times larger than the spleen the hepatic artery is prevailingly smaller in caliber than the splenic In contrast with the latter *the hepatic is seldom tortuous* the nearest approach to this condition being the caterpillarlike loops made by the right hepatic in and about the cystic triangle (see Plate II Nos 21–40 Fig 51) In 50 specimens the width of the hepatic artery varied from 4 to 12 mm the most *common width being 7 to 8 mm* as shown in the following table

TABLE 7 WIDTH OF HEPATIC ARTERY

Width in mm	4	5	6	7	8	9	10	11	12
Times	1	4	7	13	15	5	1	2	2

In all subjects at least three major hepatic arteries (right left and middle) reach the inferior surface of the liver While the three major vessels enter the porta hepatis i e the transverse cleft *between the caudate and the quadrate* lobes the left and the middle hepatics attain their ultimate distribution in the fossa for the umbilical vein (left) The right hepatic breaks up into its branches in the porta hepatis which in many livers is extended for a considerable distance laterally constituting a fissured area below the gallbladder A branch of the right hepatic to this fissured area may readily be mistaken for the cystic artery as shown in many of *the author s illustrations* (Figs 75 78 85 90 91)

Mode of Branching The mode of branching of the *right the middle* and the left hepatics as described here was worked out by dissection by the author 10 years before Healey and Schroy began investigating the mode of branching of the three respective hepatic arteries in plastic corrosion casts of human livers as described in Chapter 7 While there is a general agreement on our basic concept of the mode of branching of the major hepatic arteries there are many differences these being due largely to the fact that in the corrosion casts the finer extrahepatic branches of the hepatic arteries (especially the subcapsular kind) do not show up for the following reasons (1) in the casts many of the subcapsular branches were purposely not injected with the plastic material for, if they had been injected because of their number (65) and their *ramifications they would have obscured* vision of *the interior branching* (Figs 81 93) (2) in the making of the casts especially during the removal of excess hepatic parenchyma by manual manipulation after corrosion in hydrochloric acid many of the smaller branches because of their brittle consistency are apt to be broken (3) many of the extrahepatic branches of the hepatics especially the subcapsular types are too small in caliber to allow injected plastic material to pass into them whereas the colored embalming fluid could pass into them readily With these points in mind the following account of the extrahepatic branching of the hepatic arteries is given

In most instances the right hepatic or the aberrant right hepatic after giving off the cystic to the gallbladder, divides into two large branches (an upper and a lower in the author s illustrations) which according to the plastic casts of Healey and Schroy proved to be the anterior and the posterior segment arteries for the respective anterior and posterior segments of the right lobe (Fig 49) The middle hepatic (medial *segment artery of Healey et al*) *in the* author s extrahepatic dissections was predominantly a branch of either the right (Fig 69) or the left hepatic (Fig 73) and in its course in the umbilical

fossa supplied the quadrate lobe (medial segment of the left lobe Healey et al) by means of several branches the nature of which will be discussed later as ascertained in the plastic casts Extrahepatically the left hepatic supplies two large branches (upper and lower in the author s illustrations) which in the plastic casts of Healey and Schroy proved to be the inferior and the superior area branches of the lateral segment artery of the left lobe (Fig 77) These three major liver arteries (right middle and left hepatics) carry the main hepatic blood supply but before entering the liver very often undergo penultimate and ultimate subdivisions (Fig 85) each branch as shown by Glauser (1953) becoming distributed to a single pyramidal lobule Commonly a relatively large branch of the right hepatic runs downward in most instances behind the right branch of the portal vein to supply the caudate process at times being accompanied by a bile duct draining the same area (Fig 88)

Right Hepatic Details of the divisional patterns of the right hepatic and the relation which the artery and its extrahepatic branches have with the biliary ducts will be described later when the contents of the cystic triangle of Calot are considered

Middle Hepatic The middle hepatic (medial segment artery of Healey and Schroy) furnishes the main arterial blood supply to the quadrate lobe Although not named or described in texts of anatomy (except Morris) the middle hepatic in view of its constancy and the fact that it may supply the superficial cystic is of sufficient importance to regard it as a major constituent branch of the hepatic trunk In some instances it is the only hepatic branch arising from the common hepatic the latter dividing into the middle hepatic and the gastroduodenal the right and the left hepatics being replaced from other sources (Fig 55) In about equal proportion according to the author s 200 dissections the middle hepatic arises from the right hepatic (15 per cent Fig 69) or the left hepatic (15 per cent Fig 68) and in 10 per cent from other sources (as the celiac the gastroduodenal the hepatic or the right gastric Figs 83 67 77 59) It is accompanied by the middle hepatic duct draining the quadrate lobe

To reach the quadrate lobe the middle hepatic courses upward to the left of the hepatic duct then passes into the angle formed by the left limb of the portal vein and the umbilical ligament From here on it proceeds into the fossa for the umbilical vein (round ligament) to the right of which it intermittently and at different levels gives off small branches (3 to 7) to the left surface of the quadrate lobe and to the floor of the fossa the artery passing over or under tributaries to the left branch of the portal vein (Fig 54) Proximally it often gives off a few subcapsular branches before entering the fossa distally it ends by passing into the falciform ligament which it supplies with several branches (Fig 88) In many instances it sends a branch or two to the left lobe (Fig 60) these pass under the round ligament and may anastomose with branches from the left hepatic (Fig 84) The blood supply to the quadrate lobe may be augmented by branches from the left hepatic (Fig 51) In short just as the middle hepatic may send branches to the left lobe so the left hepatic may send branches to the quadrate lobe (Fig 71) Both arteries may participate in the blood supply of the caudate lobe and in that of the falciform ligament (Figs 70 72)

Left Hepatic According to the author s extrahepatic dissections the left hepatic usually divides into two branches an upper and a lower which in the casts of Healey and Schroy proved to be the inferior and the superior area branches of the lateral segment of the

left lobe (Figs 77 88) Before dividing into its ultimate branches the left hepatic may give origin to the middle hepatic the right gastric a branch to the caudate lobe or an accessory left gastric (Figs 18 75) The lower branch of the left hepatic (in the author s illustrations it corresponds to the superior area branch of Healey and Schroy) enters the left lobe below or above the point of entry of the lower branch of the portal vein (Figs 50 60) Frequently it bifurcates before entering and gives off subsidiary subcapsular twigs and a branch or two to the caudate lobe (Fig 75) The upper branch of the left hepatic (in the author s illustrations it corresponds to the inferior area branch of Healey and Schroy) continues onward in the fossa for the umbilical vein anterior or posterior to the portal vein and enters the liver above or below the point of entry of the upper large branch of the left branch of the portal vein (Figs 89 52) The upper branch (inferior area branch) likewise bifurcates in most instances before entering and gives off a variable number of subsidiary subcapsular twigs (Fig 77) A long slender branch from it passes over or under minor branches of the left portal vein ending in the falciform ligament which it supplies with several twigs (Fig 68)

When the left hepatic arises from the left gastric as a replaced left hepatic its mode of branching and entrance into the liver is similar to that of the celiacal hepatic with the added feature that it may give rise to the middle hepatic (Fig 55) An accessory left hepatic from the left gastric is commonly anastomosed with the lower (superior area) branch of the left hepatic the anastomosis supplying branches to the region of the left lobe of the liver (Fig 72)

Penultimate and Ultimate Branching The terminal penultimate and ultimate extrahepatic branches of the three main hepatic arteries present patterns which vary to such an extent that in 50 specimens in which the arteries were followed to their very entry into the liver no two were the same The situation is therefore comparable with that existent in the spleen where the author s studies of 100 splenic arteries revealed 100 different kinds of terminal lienal branching The terminal extrahepatic branches varied in size number topographic distribution mode of entry into the liver extrahepatic anastomoses disposition about the portal vein and its tributaries and in their relation to the biliary ducts Many of the terminals were of twig size subcapsular in course and at point of entry this being especially the case with the terminals supplying the caudate and the quadrate lobes (Figs 76 84 85)

As ascertained in a detailed dissection of 50 specimens the number of terminal branches entering the liver from all three hepatics (exclusive of those from the cystic artery) varied from 20 to 65 The higher the number the finer and the more distributed are the end branches the latter often being only subcapsular twigs As statistically computed by counting after dissection 70 per cent of the specimens had between 20 and 30 hepatic terminal arteries 10 per cent had between 30 and 40 while the others were above or below these figures The terminals were distributed selectively to definite areas of the liver a major portion of the small twigs entering the caudate and the quadrate lobes (Figs 84 85) From extrahepatic dissection then it would seem that the arterial vascularization of the liver like that of the spleen is effected in regional units each artery having a selective distribution The investigations of Healey and Schroy in liver casts and that of Glauser (1953) on roentgenograms of injected livers prove this concept to be the correct one

Blood Supply of the Caudate and the Quadrate Lobes

In considering the caudate lobe one must distinguish between its right band like caudate process and its left nodule like papillary process the two being marked off by a sulcus against which the hepatic ducts and vessels are compressed The caudate process is a long narrow strip of hepatic tissue which connects the caudate lobe to the inferior surface of the right lobe and which separates the fossa for the inferior vena cava from the fossa for the gallbladder A deep or shallow fissured area often lies above it (Fig 88) The papillary process is a knoblike mass of tissue about the size of a walnut on the posterior surface of the liver Partly swerved around the inferior vena cava its major portion is free and projects downward behind the portal fissure into the lesser peritoneal cavity (omental bursa) in which it may be felt if the finger is passed through the epiploic foramen of Winslow

The terminal branches to the caudate lobe have an extremely varied origin and distribution and have never been estimated statistically on the basis of extra hepatic dissection Sites of their origin and distribution as observed in liver casts by Healey and Schroy are described in Chapter 7 In 60 per cent of the 50 specimens in which the author painstakingly dissected the arterial blood supply to the caudate lobe the entering arteries were derived from the right hepatic or the aberrant right hepatic via a large branch which in most instances ascended to the cephalic border of the right branch of the portal vein then descended behind it giving off numerous bifurcating twigs to the caudate process in its long irregular course before ending in grapevine like distribution of twigs to the papillary process (Fig 69) In 14 per cent both the right and the left hepatics participated in the blood supply the branches from the left hepatic usually being distributed to the papillary process those from the right hepatic to the caudate process (Fig 88) In some instances the branch to the papillary process came from the right hepatic (Fig 83) In 6 per cent a middle hepatic from the right hepatic gave the supply (Fig 91) while in 4 per cent all three hepatics (right middle left) participated (Fig 49) In 8 per cent the supply was from a right and a middle hepatic in 2 per cent from the middle hepatic of a right hepatic and from the left hepatic Only in 8 per cent was the supply exclusively from the left hepatic or the hepatic (Fig 62)

The terminal branches to the caudate lobe varied from 3 to 10 the maximal being 65 (Fig 84) Prevailingly they were very short tiny twiglike subcapsular branches which bifurcated before entering They were given off intermittently to different points by the major caudate branch which in its tortuous course in all instances was closely applied to the caudate process Some of the terminal subcapsular branches were distributed beyond the papillary process to the lower end of the fossa for the ductus venosus and to the quadrate lobe (Fig 49) In many cases the small caudate branches anastomosed with one another or with branches from the right the middle or the left hepatic (Figs 52 53 57 66) It is interesting to note that in contour and mode of topographic distribution the terminal caudate branches to the posterior surface of the liver (i e caudate lobe) were similar to the crawling branches of the splenic artery which the author has described as being present on the renal (posterior) surface of the spleen (Figs 109 112)

The quadrate lobe which according to Healey and Schroy belongs to the left lobe shows a constant variation in con

tour and volume To the right it slopes off into the gallbladder bed sharply or gradually to the left its oblique often cleft wall bounds the fossa for the umbilical vein (Fig 89) The fossa is at times partly at times completely bridged by hepatic tissue (pons hepatis) (Figs 48 50) Due to the intermingling of the branches of the left portal vein with the arterial branches of the middle and the left hepatics many of which cross from side to side and anastomose the vessel content of the fossa is very complex

As stated the main arterial blood supply to the quadrate lobe is furnished by the middle hepatic which courses to the right side of the ligamentum teres (Fig 76) Often small branches from the left hepatic cross over and augment the supply just as branches from the middle hepatic may cross over or under the round ligament to enter the left lobe (Figs 74 54)

In 50 per cent of the 50 cases investigated the middle hepatic to the quadrate lobe came from the right hepatic (Fig 76) in 44 per cent from the left hepatic (Fig 88) and in 6 per cent from the celiac hepatic gastroduodenal right gastric (Figs 59 67 74) In 26 per cent there were additional branches to the quadrate lobe from the left hepatic Branches to the quadrate lobe were larger than those to the caudate—they varied in number from 3 to 7 the maximal being 14 branches to the caudate lobe varied from 3 to 10 the maximal being 15

In 20 per cent the quadrate and the caudate lobes combined had more liver branches of the hepatic artery than the rest of the liver In 16 per cent the number of branches was even and in 64 per cent the two lobes had a less number of branches However this observation does not mean that in 20 per cent the major arterial blood supply to the liver enters via the quadrate and the caudate lobes for the hepatic branches to these lobes are predominantly very small subcapsular twigs while the two main branches of the right hepatic the two branches from the left hepatic and the middle hepatic itself are decidedly larger vessels (Fig 84)

Fissured Area Below the Gallbladder In many livers there is a fissured area under or below the gallbladder (i e above the caudate process) made by a lateral extension of the porta hepatis above the caudate process The depth and the dimensions of the fissure vary considerably some being very deep with an extensive packing of omental tissue others are very shallow Commonly a branch of the celiacal right hepatic (posterior segmental branch of Healey and Schroy) enters the fissure where it becomes subdivided into smaller branches (Figs 50 63 72 74) Before or after reaching the cystic triangle an aberrant right hepatic from the superior mesenteric often gives off 2 to 3 large branches to the fissured area (Figs 85 90) Such a fissure branch from either source may readily be mistaken for the cystic especially when its course is parallel with that of the cystic duct or behind it (Fig 55) Fortunately most of these fissure branches from aberrant right hepatics are deeply situated and being covered by omental tissue are out of surgical danger provided that there is no excessive probing for the cystic Many of the fissure branches are very close to the surface and present the same surgical hazard as the relatively free branches arising from the celiacal hepatic (Fig 49) In some instances a fissure branch may give rise to the superficial cystic (Figs 85 90)

Anastomosis of the Hepatic Arteries

Of great interest and importance to the surgeon is the extent of extrahepatic and intrahepatic anastomoses of the hepatic arteries When a relatively large hepatic artery is severed inadvertently

are there sufficient collateral pathways to re establish the circulation or do areas deprived of their blood supply undergo necrosis? Are some of the so called liver deaths due primarily to an inadequate circulation effected by severance of a major liver artery such as a replaced right hepatic from the superior mesenteric? Has injury to a right hepatic artery with subsequent necrosis anything to do with the hepatorenal syndrome developed after cholecystectomy in patients who previously had normal kidneys as claimed by Ramstrom (1953)? Are some of the deaths following gastric resection due to a necrosis of the left lobe of the liver operatively induced by the accidental ligature of the left hepatic artery? What is the factual anatomic condition as regards collateral circulation when in the treatment of portal hypertension due to severe cirrhosis of the liver the hepatic artery is ligated and the patients survive (Rienhoff 1951 Philip Thorek 1953) or the patient dies (Rosenbaum and Egbert 1952)? These problems will be discussed at length in Chapter 14 As far as extra hepatic anastomoses are concerned the situation is somewhat similar to that existent in the splenic artery In the author s dissections of 100 splenic arteries (1942) it was shown that the extrasplenic anastomoses are restricted to extrahilar transverse anastomoses between the terminal branches of the splenic artery (Figs 148 151)

The extrahepatic anastomoses between the hepatic arteries comprised the following main types (1) between the major hepatic arteries i e between the right hepatic and the left or the middle hepatic (Figs 51 42) between the middle hepatic and the left hepatic (Fig 67) or between the two branches of the right hepatic (Fig 54) (2) between the right hepatic and the aberrant right hepatic from the superior mesenteric directly but only in a few cases (Figs 15 88 89) (3) between the terminal branches of the branch of epithelial outgrowth from the caudal lobe and the terminals from the middle or the left hepatic or between the terminals of the latter two arteries alone such union being very frequent in the fossa for the umbilical vein (Figs 51 52 55 57 63) (4) between the left hepatic and the left gastric via a small artery coursing in the peripheral end of the lesser omentum rather frequent (Figs 72 78 87) (5) between the hepatic or the right hepatic and the gastroduodenal the retroduodenal or the supraduodenal (Figs 51 63 67 75 79) (6) between the cystic and the common hepatic or the right hepatic (Figs 63 82)

As regards the cystic artery it rarely anastomoses with other regional arteries In one instance it was anastomosed with the right hepatic in two cases it was anastomosed respectively considered with a branch of the caudate lobe (Fig 82) and with the left hepatic (Fig 63) The superficial and the deep cystics however by means of their ramifying branches are often anastomosed at different points on both surfaces of the gallbladder (Figs 49 50 52)

Blood Supply of the Biliary Ducts

The mode of division and distribution of the right the middle and the left hepatic arteries are accompanied by similar divisions of the hepatic duct and will be described in detail in Chapter 7 according to findings in the liver corrosion casts of Healey and Schroy As observed in the author s dissections the right hepatic duct divides into an anterior and a posterior main trunk both of which receive twigs from the right hepatic The middle hepatic duct (a branch of the left hepatic duct) courses in the umbilical fossa to drain the quadrate lobe and receives rami from the middle hepatic artery The left hepatic

duct divides into an upper (inferior area branch) and a lower (superior area branch) main duct which drain the left lobe both receiving twigs from the left hepatic artery Ducts draining the caudate lobe take the same course as the arteries a common pattern being one in which a duct from the right hepatic duct drains the caudate process a duct from the lower division of the left hepatic duct (superior area duct) draining the papillary process

The biliary ducts receive their blood supply by means of fine arterial twigs given off at different levels by the regional arteries Such twigs arise prevailingly from the right hepatic the middle hepatic the left hepatic the cystic the gastroduodenal the supraduodenal and the retroduodenal the latter often sending a fairly large branch upward another downward to the common bile duct (Figs 52 58 61 99) The intrapancreatic portions of the common bile duct receive branches from the anterior and the posterior duodenal arcades On all ducts the arterial twigs undergo repeated branching and often are united in plexiform manner as are the branches of the cystic on the anterior and the posterior surfaces of the gallbladder (Fig 99)

The Portal Vein Its Relations and Tributaries

The portal vein (cor abdominale vena arteriosa of ancient writers) is formed by the union of the splenic and the superior mesenteric veins behind the isthmus of the pancreas The ancient concept that the portal vein resembles a tree in that its roots ramify in the intestinal tract while its terminal branches arborize in the liver like a tree is anatomically correct for the portal vein branches and capillarizes in the liver substance like an artery In its ascent to the liver the portal vein passes behind the first part of the duodenum then accompanied by the common bile duct and the hepatic artery it courses between the two layers of the lesser omentum (in the hepatoduodenal ligament) in front of the foramen of Winslow From its point of origin to its terminal branching in the porta hepatis it measures from 8 to 10 cm its width varying from 8 to 11 mm Reaching the porta hepatis it becomes dilated horizontally to a varying degree then abruptly divides into a short broad right branch and into a longer and narrower left branch (Figs 19 87) The latter after receiving a tributary from the caudate lobe enters the left sagittal fossa of the liver where as a rule it receives two large tributaries from the left lobe and one or two from the quadrate lobe (Fig 88) In the fossa it is joined by a fibrous cord the round ligament (ligamentum teres hepatis) a remnant of the left umbilical vein Another fibrous cord the ligamentum venosum to which the hepatogastric ligament is attached, proceeds from the left branch of the portal vein to the left hepatic vein which unites with the inferior vena cava (Figs 83 89)

Tributaries to the portal vein vary considerably As shown by Douglass Baggenstoss and Hollinshead (1950) at the Mayo Clinic these variations are extremely important in operative procedures to produce a shunting of the portal blood flow in order to ameliorate portal hypertension Various veins of the portal system (splenic superior mesenteric and the portal itself) have been joined surgically with veins of the inferior caval system In their study of 92 specimens Douglass et al noted that the portal vein receives the superior pancreaticoduodenal the pyloric vein and frequently the coronary (24 per cent) and an accessory pancreatic (31 per cent) In 38 per cent the superior pancreaticoduodenal was single in 50 per cent it was double one terminating in

the portal vein the other in the superior mesenteric The right gastro epiploic terminated in the superior mesenteric in 83 per cent in some instances it joined the base of the splenic and the first part of the portal (2 per cent) The coronary vein terminated in the superior aspect of the junction of the splenic and the superior mesenteric (58 per cent) in the portal vein (24 per cent) in the splenic distal to its junction with the superior mesenteric (16 per cent) The pyloric vein (right gastric) could not always be identified Usually small it terminated in the portal vein within 3 cm of its division into right and left branches (75 per cent) at the base of the superior mesenteric (22 per cent) in the proximal segment of the right gastro epiploic (2 cases) in the inferior pancreatic duodenal (3 cases) and in two instances it had a common termination with the coronary vein The inferior mesenteric terminated most commonly (38 per cent) in the splenic vein at times 3 4 cm from the latter s junction point In 32 per cent it terminated at the junction of the two veins and in 29 per cent in the superior mesenteric itself In three instances it was double The splenic vein (average length 15 cm) was formed by the convergence of several trunks (2 to 6 usually 3) which in different divisional patterns emerged fanlike from the hilus A superior polar vein was found in 7 cases The short gastric veins terminated in the upper posterior part of the spleen or its hilus in 62 per cent and only in the lower anterior portion in 27 per cent Many of the short gastrics emptied directly into the spleen

Madden of St Clare s Hospital New York (1952) by means of injected latex specimens demonstrated pre existing postcaval shunts (e g between the fundus of the stomach and the left adrenal vein between an intestinal vein in the mesentery of the terminal ileum and the right ovarian vein) Such pre existing postcaval shunts in his opinion might be the reason why some patients with severe portal cirrhosis have neither ascites nor esophageal varices

For an exhaustive literature review of the functional anatomy of the porta systemic communications the reader is referred to the splendid work of Edwards (1951) who on the basis of his own research maintains that the deep path ways of the porta systemic communications are normally patent and of greater significance than the anterior parietal

For the major portion of its course according to the author s dissections the vertical or ascending portion of the hepatic artery as a rule lies anterior to the portal vein and to the left of the common bile duct in the hepatoduodenal ligament (Figs 57 59) At the porta hepatis its three main branches (right left and middle hepatics) have a similar anterior relation to the portal vein or to the latter s right and left branches The horizontal or proximal part of the hepatic artery on the contrary for the most part lies to the left of the portal vein covered by pancreatic tissue (Fig 52) At its origin from the celiac it courses to the right in an arched fold of the posterior parietal peritoneum—the plica hepatopancreatica—whereby it reaches the hepatoduodenal ligament

Division point of the hepatic artery into its main branches as it lies on the portal vein varies in all instances and accounts for the varied lengths of the right the left and the middle hepatic arteries The division point may be low high or intermediate depending on the length of the hepatic segment that is left after the gastroduodenal has been given off (usually to the left of the portal vein) (Figs 50 86) Site of the bifurcation of the hepatic into its right and left branches occurs most commonly at or somewhat below the level of the junction of the cystic duct with the hepatic duct the left hepatic often crossing the

caudate process to reach the left lobe the right hepatic crossing the hepatic duct posteriorly (85 per cent) at a varied point to reach the cystic triangle In contrast with the anterior portal relation of the hepatic and its three main branches the ultimate and the penultimate hepatic branches intermingle with the tributaries of the portal vein this being markedly the case in the fissured area above the caudate process and in the fossa for the umbilical vein (Figs 81 93)

Aberrant right hepatics from the superior mesenteric in most instances proceed upward dorsal to the portal vein (Figs 81–90) When the right hepatic arises from the celiac independently of the left hepatic it invariably courses dorsal to the portal vein (Fig 83) The branch to the caudate lobe, when supplied by the right hepatic usually descends behind the portal vein giving off arterial twigs to the caudate process before ending in the papillary process (Fig 69) A branch to the fissured area below the gallbladder may arise from the hepatic or the right hepatic to the left of the portal vein then pass dorsal to it thus placing the portal vein in an arterial loop the right hepatic lying anterior (Fig 75) In one case a double portal vein was observed the hepatic duct being sandwiched between the two portal systems (Fig 37) The anomaly is very rare for it was seen only once in 500 bodies It may be noted here that the entry point of the retroduodenal vein from the posterior surface of the duodenum and the head of the pancreas is into the portal vein the entry point being similar and about at the same level as the coronary vein (Fig 37)

The Aberrant Hepatic Arteries

An aberrant hepatic artery as stated is a hepatic arising otherwise than from a typical celiacal hepatic Thus a right hepatic artery becomes aberrant when it takes origin from the aorta the superior mesenteric the left gastric the retroduodenal the gastroduodenal the superficial cystic the dorsal pancreatic or when it arises aberrantly (i e independently of the left hepatic from a celiac trunk) (Figs 66 84 51 18 91 34 73) A left hepatic becomes aberrant when it has an origin from the left gastric the aorta the splenic or the superior mesenteric (Figs 76 66, 53) Aberrant hepatic arteries comprise two types viz replaced and accessory (Figs 81 86) A replaced hepatic is a substitute for the normal hepatic which is lacking an accessory hepatic is additive to the one which is normally present and is often smaller but nevertheless is essential functionally it having its specific distribution in every case

Of the 200 bodies statistically estimated 83 (41.5 per cent) had one or more aberrant hepatics while 117 (58.5 per cent) had none In all 106 aberrant hepatic arteries were encountered in 83 bodies of which 63 bodies (31.5 per cent) had 1 (accounting for 63) 17 bodies (8.5 per cent) had 2 (accounting for 34) and 3 bodies (1.5 per cent) had 3 (accounting for 9) Failure of authors to differentiate between the total number of aberrant hepatics observed in a given investigation (e g sample of 50 or 100 bodies) and the number of bodies actually possessing one or more aberrant hepatics accounts in part for the discrepancy in figures in the literature for percentages of aberrant and accessory hepatics From the present statistical study it may be concluded that some sort of aberrant hepatic artery (either replaced or accessory) occurs approximately in every other body (41.5 per cent) and that 31.5 per cent have but one aberrant hepatic while 10 per cent have two or more

Aberrant hepatics fall into two main groups viz aberrant right hepatics and aberrant left hepatics In either case they may be replaced or accessory (Figs

81 86 76 19) In 200 specimens 52 (26 per cent) aberrant right hepatics were encountered of which 36 were replaced and 16 were accessory 54 (27 per cent) aberrant left hepatics were found including 31 replaced and 23 accessory

The above data may be schematized as follows

Aberrant RH in 200 bodies: Re RH = 18% (36 cases); Ac RH = 8% (16 cases); Totals 26% (52 cases)

Aberrant LH in 200 bodies: Re LH = 15 5% (31 cases); Ac LH = 11 5% (23 cases); Totals 27% (54 cases)

	Re RH				Re LH		
From	SM	Cel	Aorta	LG	LG	SM	Aorta
Cases	25	6	4	1	23	5	3
Per Cent	12 5	3	2	0 5	11 5	2 5	1 5

	Ac RH					Ac LH
From	SM	RD	DP	RG	Cel	LG
Cases	9	4	1	1	1	23
Per Cent	4 5	2	0 5	0 5	0 5	11 5

In 9 bodies the common hepatic trunk was replaced from some other source in 3 bodies from the aorta (Plate II No 21) in 5 bodies from the superior mesenteric (Figs 38 53) in 1 body from the left gastric (Fig 20) The right hepatic alone may be replaced from the aorta in which case the left hepatic arises from the left gastric (Fig 66)

The most common site of origin of an aberrant right hepatic is the superior mesenteric (Fig 87) for an aberrant left hepatic it is the left gastric (Fig 76) Of the 46 cases having an aberrant left hepatic from the left gastric 23 were replaced left hepatics (Fig 95) 23 were accessory left hepatics (Fig 86) The proportion of accessory and replaced types therefore is equal in the sample studied Of the 34 cases having aberrant right hepatics from the superior mesenteric 25 were replaced right hepatics (Fig 85) and 9 were accessory right hepatics (Fig 88) The proportion of the replaced variety here definitely surpasses that of the accessory type

Functionally estimated nearly every other aberrant left hepatic arising from the left gastric (23 per cent of all bodies dissected) constitutes the only left hepatic present and three fourths of the aberrant right hepatics derived from the superior mesenteric (17 per cent of all bodies) are replaced right hepatics

In view of this precarious anatomy the surgeon performing a gastrectomy should investigate every instance of a left hepatic arising from the left gastric since in one half of the cases when present it is the only artery supplying

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In view of this precarious anatomy the surgeon performing a gastrectomy should investigate every instance of a left hepatic arising from the left gastric since in one half of the cases when present it is the only artery supplying

the left lobe (Fig 76)—it may even be the entire hepatic trunk having such origin as observed in 1 case (Fig 20) When a right hepatic arises from the superior mesenteric (Fig 81) the danger of depriving the right lobe of its blood supply is even greater since in the majority of cases *it is the only right hepatic* present only one fourth of this type of artery being accessory (Fig 86) In the absence of a celiacal hepatic trunk the common hepatic may arise from the superior mesenteric (5 cases) and in some instances pass through or behind the head of the pancreas (Fig 38) Severance of such a replaced hepatic trunk would result in immediate death of the patient

Little need be said with regard to aberrant right hepatics having an origin other than from the superior mesenteric *or the celiac In most instances they* are small hepatic branches arising from the gastroduodenal via its retroduodenal branch or from the right gastric or from the dorsal pancreatic (Figs 91 39) That damage would ensue to the liver by severance of these small accessory hepatics is obvious from the plastic casts of Healey and Schroy where each hepatic artery has a selective distribution Ruthless clamping or sacrifice of these accessory small hepatics should be avoided for in some instances they supply the superficial cystic artery the deep cystic arising from the main right hepatic

Except for the percentage of accessory left hepatics the author's calculations as regards occurrence of aberrant hepatic arteries are *in conformity with those* given by Daseler Anson Hambley and Reimann (1947)[1] In an examination of 500 bodies they found 84 cases (16 8 per cent) of replaced right hepatics 36 cases (7 2 per cent) of accessory right hepatics—a total of 120 aberrant right hepatics with a total percentage of 24 (the author's is 26 per cent) As regards aberrant left hepatics Daseler Anson Hambley and Reimann observed 18 per cent *(90 cases) of replaced left hepatics* as opposed to the author's 15 5 per cent, and 35 per cent (175 cases) of accessory left hepatics as opposed to his 11 5 per cent

This striking difference in percentage of accessory left hepatics is due to the fact that Daseler Anson Hambley and Reimann regarded many of their accessory left hepatics as a branch of the right hepatic (19 8 per cent 99 cases) or as a branch of the common hepatic (2 2 per cent 11 cases) The author interpreted such branches as middle hepatics (for *quadrate lobe) and did not consider* them as accessory left hepatics If then their total 22 per cent of such accessory left hepatic arteries (branch of the right hepatic 99 cases or common hepatic 11 cases—19 8 per cent + 2 2 per cent = 22 per cent) is deducted from their total of 35 per cent of accessory left hepatics the percentage of the latter is reduced to 13 per cent which conforms well with the author's percentage of 11 5 per cent for accessory left hepatics In short Daseler Anson Hambley and Reimann would then have 155 cases of aberrant left hepatics (90 Re l H or 18 per cent 65 Ac l H or 13 per cent) giving a total percentage of 31 which is only four points higher than the author's (27 per cent) That this categorization of *their accessory left hepatics* is in the main a correct one is confirmed by their report that in 54 cases (10 8 per cent) the accessory left hepatic came from the left gastric The author's percentage for the same finding is 11 5 per cent a difference of less than 1 per cent

[1] From the anatomical laboratories of the Northwestern University Medical School

The Cystic Artery

Typically the cystic artery arises from the celiacal right hepatic to the right of the hepatic duct in Calot s (1890) tri angle The boundaries of this triangle are inferolaterally the cystic duct medially the hepatic duct cephalad the liver the right hepatic and the cystic arteries being located prevailingly in the upper part of the triangle (Figs 2 51)

After a short medium or long course the cystic artery usually divides into a superficial (anterior) and a deep (pos terior) branch these being the Cysticae gemellae of Vesalius (1561) The super ficial or anterior branch is distributed to the free peritoneal surface of the gall bladder the deep or posterior branch to the attached nonperitoneal surface and to the gallbladder bed The branches anastomose at various points and give off numerous twigs to the liver surface underlying and adjacent to the gallblad der bed twigs from the superficial cystic being distributed to the lateral side twigs from the deep cystic to the medial side of the gallbladder or vice versa (Figs 50 67) In about one fourth of the subjects (25 per cent) however the superficial and the deep branches of the cystic artery have a separate origin the deep cystic as a rule arising from the right hepatic the superficial cystic from the right hepatic or from some other source (middle hepatic left hepatic gas troduodenal retroduodenal) (Figs 77 30 46 64) Resultant anatomy is the prevalence not of a fortuitous but of a frequent dual blood supply to the gall bladder (double cystic artery)

In the following text statistics are based on 200 dissections of adult bodies Plate No references are those of Plates I–VI in which in small schematic sketches variations or origin of the cystic artery and the varied relations of the bile ducts to hepatic and cystic arteries are depicted

Single Cystic Artery In the 200 bodies statistically estimated the cystic artery was single in 75 per cent in 25 per cent it was double the latter including one triple cystic (Plate V No 81) In 140 of 200 subjects (70 per cent) the single cystic was a branch of the right hepatic (including its varieties replaced or ac cessory right hepatics from the superior mesenteric the aorta or the celiac (Plate III Nos 47 52 Plate II No 21 Plate III No 44) and in only 5 per cent it arose from some other source (left he patic middle hepatic hepatic retro-duodenal gastroduodenal (Plate IV Nos 61–64 66 67 Plate VI Nos 101 102) The site of origin of the single cystic occurred in the cystic triangle in 57 per cent of the 200 cases viz from the celiacal right hepatic or its branches 43 per cent (86 cases Plate I Nos 1 15) from a replaced right hepatic 13 per cent (26 cases Plate III No 47) from an accessory right hepatic 1 per cent (2 cases Plate III No 52)

An origin of the single cystic from the right hepatic to the left of the hepatic duct occurred in 13 per cent (26 cases in 200 Plate IV Nos 69–78) and to the left of the hepatic duct or the common bile duct from other sources in 5 per *cent (10 cases Plate IV Nos 61–74* Plate VI Nos 101 102) making a total of 18 per cent in which a single cystic because of its origin to the left of the bile duct system had to cross the hepatic duct or the common bile duct (in most cases anteriorly) to reach the gallbladder

In 112 cases (56 per cent) the single cystic arose from a typical celiacal right *hepatic (43 per cent inside as in Plate* III No 56 13 per cent outside of Calot s triangle as in Plate IV No 69) Thirty eight cases (19 per cent) represented single replaced cystic arteries i e a cystic arising otherwise than from a typical celiacal right hepatic Sources of

origin of the single replaced cystic to the *left of the hepatic duct* were the middle hepatic 2 per cent (Plate IV, *Nos 62–64*) left hepatic, 1 *per cent* (Plate IV No 61) hepatic trunk, 1 per cent (Plate IV *Nos 66 67*) gastroduodenal or its retroduodenal *branch 1* per cent (Plate VI *Nos 101, 102*)

Sources of origin of the *single replaced* cystic from a right hepatic *other than* the *typical right celiacal* hepatic were (a) a *right hepatic replaced* i e arising *independently of the left hepatic from the celiac and coursing behind the portal* vein (3 per cent 6 cases Plate III No *14*) (*b*) a replaced right *hepatic* arising from the superior mesenteric (6 5 per *cent 13* cases *Plate III* No *17*) (c) an accessory right hepatic arising from the superior mesenteric (1 per cent, 2 cases Plate III *No* 52) (d) a right hepatic of a common hepatic derived from the superior mesenteric (2 5 per cent 5 *cases Plate III No 13*) (e) a right hepatic of a hepatic trunk arising directly *from the aorta* (*1* per cent 2 cases *Plate II No 21*)

In summary then of the replaced single cystics 10 per cent arose from an aberrant right hepatic from the superior *mesenteric* 5 per cent from an artery other than the right hepatic (*i e* from *left hepatic middle* hepatic, hepatic, gastroduodenal or retroduodenal) 1 per cent from a right hepatic arising independently from the celiac or from the aorta making a total of 19 per cent (38 of 200) in which the single cystic was replaced from an artery other than the typical celiacal right hepatic In one case the single cystic had a dual origin (Plate VI No 110) one branch arising from the left hepatic to the left of the hepatic duct the other from the right hepatic in Calot s triangle After fusion of the two branches the common vessel supplied the gallbladder A comparable situation was observed in the variety of dual cystics the superficial cystic being anastomosed with a branch of the *left hepatic which supplied the* caudate lobe (Plate VI No 109)

Double Cystic Artery The Cysticae gemellae of Vesalius (1564) In 50 cases of the 200 cases statistically estimated the superficial and the deep branches of the cystic artery arose separately from the same artery (see Plate III No 51) or from different sources (see Plate V No 93) This percentage of dual cystic arteries (25 per cent) is considerably higher than that reported by other authors (Lipshutz 11 per cent Rossi and Cova 11 5 *per cent*, Sousloff 12 per cent Rio Branco 12 *per cent* Daseler et al 14 per cent Flint 15 per cent Descomps 18 per cent *Belou 19* per cent 1915 *Brewer 20 per cent* Browne 21 per cent) The higher incidence *is due to the fact that in this series* the hepatic branches *were dissected up* to their very *entry into the liver Often* a high hidden cystic, usually the deep branch was thus encountered Again points of origin of the two cystics from the right hepatic in some instances were so close as to simulate one cystic artery when actually two cystics were present (Plate V No 84) A body may have three cystics (1 case of this series [Plate V No 81] that of Daseler et al that of Brewer *4 cases of Browne hence 7 in about 2 500 subjects*)

The 50 cases of double cystics comprised *12 types* Analysis of these reveals that in *48* cases (24 per cent of 200) one of the double cystics (superficial or deep) or both took origin from a right hepatic or an aberrant right hepatic in Calot s triangle Variations comprised 22 cases with the deep and superficial cystics from the right hepatic (Plate V No 82) 15 cases with the deep cystic from the right hepatic (Plate V No 90) 3 cases with the superficial cystic from the right hepatic (Plate V No 91) making a total of 40 cases (20 per cent of 200)

in which the superficial or the deep or both the superficial and the deep cystic arose from the celiacal right hepatic in the triangle Cystics from aberrant right hepatics in the triangle comprised 8 cases (4 per cent) viz 5 cases with the superficial and the deep cystic from a replaced right hepatic derived from the superior mesenteric (Plate V No 85) 1 case with the superficial cystic from a replaced right hepatic derived from the superior mesenteric (Plate V No 93) 1 case with the superficial cystic from an accessory right hepatic derived from the superior mesenteric (Plate V No 92) 1 case with the superficial and the deep from a replaced right hepatic derived from the aorta (Plate V No 87)

Otherwise stated there were 29 cases in 200 bodies (14 5 per cent) in which Calot s triangle contained the site of origin of both the superficial and the deep cystic 14 cases (7 per cent) with origin of only the deep cystic and 5 cases (2 per cent) with origin only of the superficial cystic Of the 50 cases with double cystics only 2 therefore did not contain the origin of a cystic from the right hepatic in the triangle (Plate V No 97 Plate VI No 107)

A common pattern of the dual cystics (8 of 50) is the one in which the deep cystic arises in the triangle from a celiacal right hepatic the superficial from the right hepatic to the left of the hepatic duct which it crosses anteriorly (Plate V No 90) In 4 cases the deep cystic artery arose from the right hepatic to the left of the hepatic duct (Plate V No 92) and in 1 case both the superficial and the deep had this origin (Plate V No 97) making a total of 13 (6 5 per cent in 200) in which the superficial or the deep or both the superficial and the deep crossed the hepatic duct because of its origin from the celiacal right hepatic to the left of the hepatic duct Such a crossing of the hepatic duct was also effected in 2 cases by the deep cystic arising from the middle hepatic (Plate V No 91) and in 1 case by the superficial cystic arising from the common hepatic (Plate IV No 68)

Another fairly common pattern (6 cases 3 per cent of total) of the dual cystics is the one in which the deep cystic arises in the triangle from the right hepatic the superficial from the gastroduodenal or its retroduodenal branch (Plate VI No 106) The retroduodenal instead of coming from the gastroduodenal as it usually does may arise high from the right hepatic (Plate VI No 103) or low from the superior pancreaticoduodenal (Plate VI No 105) This pattern of a superficial cystic (6 cases Plate VI No 106) or even of the entire cystic (2 cases Plate VI No 101) arising from an intestinal artery (i e from the retroduodenal) is very important from a surgical point of view for ordinarily the surgeon does not look for a cystic artery caudad to the cystic duct

Instances of a replaced type of cystic artery in the variety of dual cystics comprised 17 cases (8 5 per cent) of the 200 bodies There were 8 cases (4 per cent) with replaced cystics from an aberrant right hepatic (Plate V No 85) 6 cases (3 per cent) with replaced cystics from the gastroduodenal or its retroduodenal branch (Plate VI No 104) and 3 cases (1 5 per cent) with replaced cystics from the middle or the common hepatic (Plate V No 91 Plate IV No 68)

A report of surgical interest is the fact that in 14 cases (7 per cent) the superficial cystic swung caudally around the proximal end of the cystic duct i e left Calot s triangle to reach the peritoneal surface of the gallbladder (Plate I No 4 Plate V Nos 81 83) Such laterally swinging and hidden cystics may be severed readily when the peritoneal surface of the gallbladder is incised laterally Another oddity and surgical hazard is the criss-crossing of the superficial and the deep cystics in Calot s triangle or

outside of it (Plate V Nos 97–99) In one case the dual blood supply to the gallbladder was extremely difficult to ascertain due to the fact that the gall bladder was hidden behind the duodenum and the transverse colon to such an extent that, on opening the abdomen it seemed to be absent (Plate VI No 100)

Combined Percentage of Single and Dual Cystic Arteries

To anatomists and surgeons alike it is somewhat of a surprise to learn that in a sample of 200 bodies there were 38 cases (19 per cent) in which Calot s triangle did not contain the site of origin of a cystic artery leaving 81 per cent (162 cases) in which it did There were 86 cases (43 per cent) in which the single cystic arose in the triangle from the celiacal right hepatic (Plate I, No 1) and 40 cases (20 per cent) in which the superficial or the deep or both the superficial and the deep had the same origin hence a total of 126 cases (63 per cent) in which one or two cystics arose from a typical celiacal right hepatic (Plate V No 82)

There were 26 cases (13 per cent) in which the single cystic arose from the celiacal right hepatic to the left of the hepatic duct (Plate IV Nos 69–78) and 13 cases (6 5 per cent) in which the superficial (Plate V No 95) or the deep (Plate V No 92) or both the superficial and the deep (Plate V No 97) had the same origin making a total therefore of 39 cases (19 5 per cent) in which a cystic arose from the right hepatic before the latter crossed the hepatic duct posteriorly or anteriorly Adding the respective percentages of 63 and 19 5 gives a total of 82 5 per cent (165 of 200), in which one or two cystics arose from a typical celiacal right hepatic inside or outside the cystic triangle

Cystics from aberrant right hepatics comprised 24 cases (12 per cent) in which one or two cystics arose from a replaced right hepatic derived from the superior mesenteric (Plate I No 9 Plate V No 83) 3 cases (1 5 per cent) in which a cystic arose from an accessory right hepatic derived from the superior mesenteric (Plate III No 50) and 10 cases (5 per cent) in which the cystic arose from a right hepatic derived from a source other than the superior mesenteric viz from a replaced right hepatic from the celiac (Plate III No 44) from the aorta (Plate II No 21) or, as in one case from the left gastric as illustrated in the large drawing Figure 20

Cystics from an artery other than the right hepatic comprised 10 cases (5 per cent) in which the cystic arose from the middle or the left hepatic (Plate IV Nos 61–64) or was associated with the left hepatic by anastomosis (Plate VI Nos 109 110) 3 cases (1 5 per cent) in which a cystic took origin directly from the common hepatic (Plate IV Nos 66 67) and 8 cases (4 per cent) in which a cystic arose from a gastroduodenal or its retroduodenal branch (in 2 cases the entire cystic as in Plate VI Nos 101 102 in 6 cases only the superficial as in Plate VI Nos 104 107)—a total of 21 cases (10 5 per cent)

The total incidence of replaced cystics comprised 38 cases (19 per cent) of replaced single cystics and 17 cases (8 5 per cent) in which one or both of the dual cystics were replaced making a total of 55 cases in 200 (27 5 per cent) in which a cystic took origin from a source other than the typical celiacal right hepatic

A crossing of the hepatic duct by a cystic (Plate IV Nos 61–80) was encountered in 50 cases (25 per cent) to which must be added 2 cases in which the cystic with an origin in the triangle was anastomosed with the left hepatic and therefore crossed the hepatic duct via this anastomosis (Plate VI Nos 109 110) (Total crossings 52 cases or 26 per cent) Single cystics crossed the he

patic duct anteriorly when they arose to the left of the hepatic duct from the right hepatic (13 per cent) or from other sources (1 per cent) as from the left hepatic the middle hepatic or the hepatic Of the dual cystics 6 5 per cent represented instances in which the superficial or the deep cystic or both arose from the right hepatic 1 5 per cent in which one of the dual cystics arose from the middle hepatic or the hepatic Only 1 case was seen with both cystics crossing (Plate IV No 80) A crossing of the common bile duct by a cystic was encountered in 8 cases In 2 cases it was the entire cystic (Plate VI Nos 101 102) in 6 cases it was the superficial cystic derived from the gastroduodenal or its retroduodenal branch (Plate VI Nos 104 107)

Twelve Types of Cystic Arteries Statistically Required

The types of cystic arteries encountered vary to such an extent that in many instances it was extremely difficult to classify them The fact that 50 cases of the 200 statistically estimated (25 per cent) had two cystic arteries made a recording of percentages a further problem Obviously in considering a case with dual cystic arteries where the deep cystic arises from the right hepatic in Calot s triangle and the superficial cystic arises to the left of the hepatic duct from the middle or left hepatic or even from the gastroduodenal or its retroduodenal branch (Plate VI No 103) that case must be entered into the percentage column of different types of cystics Thus when typical cystics from the right hepatic in Calot s triangle are considered the case must be entered in this category because of its deep branch but because of its superficial branch it must likewise be placed in a percentage column of cystics arising to the left of the hepatic duct or from the gastroduodenal Again a case having a cystic from a right hepatic replaced i e arising separately from the celiacal trunk (Plate III No 11) must be entered into the percentage column of cystic arteries arising from a right hepatic in Calot s triangle as well as in the percentage column of replaced cystics

To obviate any misundertanding the author has listed both the number of cases in which a type has been observed and the percentage value of this observation as estimated in 200 bodies With these facts in mind he will categorize his observed types of cystics with the 12 types outlined by Daseler Anson Hambly and Reimann in their study of 580 cases (1947) the present author adding where deemed explanatory the percentages of other authors (total 2 000 bodies)

Type I The cystic artery arises from a typical celiacal right hepatic or its branches in Calot s triangle i e to the right of the hepatic duct and above the cystic duct (63 per cent 126 cases of 200) In this lot there were 86 cases (43 per cent) in which the cystic was single (Plate I No 1) 23 cases (11 5 per cent) in which it was double (Plate V No 82) with 1 triple (Plate V No 81) and 17 cases (8 5 per cent) in which either the superficial or the deep cystic took such origin (Plate V Nos 89 90)

The 63 per cent incidence compares favorably with that given respectively by Daseler et al (58 6 per cent in 580 bodies) Lipshutz (65 per cent in 83 bodies) and Thompson (68 per cent in 50 bodies) However it is decidedly lower than that given by Belou (70 per cent in 150 subjects) Flint (82 5 per cent in 200 bodies) Susloff (81 3 per cent in 131 cases) and Rossi and Cova (82 3 per cent in 96 subjects) The discrepancy of percentages apparently is due to the fact that authors with higher figures did not make a distinction between cystics arising in the triangle from a celiacal right hepatic and those arising

from an aberrant right hepatic If both types are included then in the author's statistical estimate Calot's triangle contained the site of origin of a cystic artery in 81 per cent of 200 cases, for in 36 cases (18 per cent) one or two cystics arose from an aberrant right hepatic in Calot's triangle (63 per cent + 18 per cent = 81 per cent) As previously stated it is a surprise to learn that in so high a percentage as 19 per cent (38 cases) *Calot's triangle was not the site of origin of the cystic artery*

Type II A single cystic arises from the right hepatic to the left of the hepatic duct i e before the right hepatic has crossed the hepatic duct posteriorly or anteriorly (13 per cent 26 cases in 200) (Plate IV, Nos 69–78) Of the double variety of cystic arteries there were 13 cases (6 5 per cent of 200 bodies) in which one of the cystics had this origin 9 cases with the superficial cystic arising in this manner (Plate V, No 90) 3 cases with the deep cystic (Plate V No 92) and 1 case in which both the superficial and the deep had this origin (Plate V No 97) In 39 cases therefore of 200 (19 5 per cent) a cystic artery (single superficial or deep branch) arose from the right hepatic to the left of the hepatic duct) The incidence of a single cystic artery of type II as reported by Daseler et al is 13 1 per cent which conforms fully with the author's observation of 13 per cent (Below 3 cases 2 per cent)

Type III A cystic artery arises in Calot's triangle from an aberrant right hepatic derived from the superior mesenteric (11 per cent Plate III No 47) or from the right hepatic of a replaced common hepatic derived from the superior mesenteric (2 5 per cent 5 cases Plate III No 42) making a total of 13 5 per cent (27 cases of 200) The author's percentage of cystics from replaced right hepatics derived from the superior mesenteric (11 per cent) is practically the same as that given by Daseler et al—viz, 11 9 per cent (Below 11 per cent)

Type IV Cystic from the left or the middle hepatic There were 6 cases in which the single cystic took origin from the left or the middle hepatic (Plate IV Nos 61–64) and 2 cases (Plate IV No 65) in which one of the dual cystics had this origin making a total of 8 subjects or 4 per cent In all instances the cystic after its origin from the left or the middle hepatic crossed the hepatic duct anteriorly in its course to the gallbladder If the 2 cases are included in which the cystic that was given off in the triangle was anastomosed to the left hepatic (Plate VI Nos 109 110) then the total incidence of a cystic from the left or the middle hepatic is 5 per cent Daseler et al found an incidence of 6 2 per cent in which the cystic came from the left hepatic (Flint 3 per cent Thompson 4 per cent Lipshutz 11 per cent) Below observed 2 cases of a single cystic from the left hepatic 1 case of a single cystic from the middle hepatic and 1 case of dual cystics in which the inferior cystic came from the left hepatic

Type V Cystic from the common hepatic trunk In the author's sample of 200 only 3 instances of such origin were encountered In 2 cases it was the single cystic (Plate IV Nos 66 67) and in 1 case it was the superficial of the dual variety of cystics with a supraduodenal branch (Plate IV No 68) Daseler et al reported an incidence of 16 cases The discrepancy is due undoubtedly to the method of regarding the exact site of origin and the nature of a given artery for Daseler et al state that in 13 of their 16 cases the cystic from the hepatic took origin near its bifurcation point into the right and the left hepatics In only 3 of their cases was the cystic a long narrow branch from the proximal part of the hepatic Thompson observed 5 instances in 50 cases and calls attention to

existent discordant percentages as regards the origin of the cystic from the common hepatic Belou observed 7 cases in 150 bodies (4 66 per cent)

Thompson compiled a total of 19 cases in 578 bodies as having been observed by various authors Categorization here is often difficult and open to question Thus the superficial cystic which the author listed as arising from the common hepatic could by virtue of its supraduodenal branch equally well be regarded as a cystic arising from the supraduodenal which artery in turn came from the common hepatic (Plate IV No 68)

Type VI Origin of a cystic artery from the gastroduodenal or from its retroduodenal branch occurred in 8 cases (4 per cent) of the 200 bodies In 2 cases it was the entire cystic (Plate VI Nos 101 102) In 6 cases it was the superficial cystic of the dual variety which took this origin (Plate VI Nos 103–107) In 5 cases the deep cystic arose in the triangle from the right hepatic In 1 case the deep cystic came from the right hepatic to the left of the hepatic duct (Plate VI No 107) The percentage of type VI listed by Daseler et al is 2 6 per cent (Thompson 1 per cent Lipshutz 3 per cent Belou 4 per cent Brewer 5 per cent Flint 12 per cent)

Type VII A direct origin of the cystic from the celiac was not observed Daseler et al reported 2 cases Belou saw none

Type VIII A cystic from a replaced or an accessory type of right hepatic derived from a source other than the superior mesenteric occurred in 10 cases (5 per cent) Of these there were 6 cases in which the right hepatic with the cystic was replaced i e arose separately from the celiac the right hepatic in all these instances passing dorsal to the portal vein (Plate III No 44) 2 cases in which the single cystic (Plate II No 21) and 1 case in which the dual cystics arose from a replaced right hepatic derived from the aorta (Plate V No 87) and one case in which the cystic arose from a replaced common hepatic derived from the left gastric as shown in the large drawing Fig 20 Daseler et al listed 3 cases of type VIII Belou none

Type IX A cystic arising directly from the superior mesenteric was not observed Daseler et al reported 1 case Lipshutz 3 Brewer 1 Browne 1 Susloff 1 Belou 1 Vincents 2—making 10 cases in over 2 000 specimens variously examined by different authors Flint and Thompson did not encounter this type

Coming very close to the type is one of the author s cases of double cystics (not listed in the percentage column) in which a very large cystic took origin from the proximal part of a gastroduodenal which came from the superior mesenteric (Plate VI No 108 also Fig 46) The usual gastroduodenal from the hepatic was small and anastomosed with the large replaced gastroduodenal arising from the superior mesenteric The replaced gastroduodenal passed behind the head of the pancreas swung around the lateral side of the common bile duct and came to the ventral surface of the pancreas where it divided into the superior pancreaticoduodenal and the right gastro epiploic—(incidentally such a disposition of the gastroduodenal could cause an intermittent jaundice) The superficial cystic passed behind the head of the pancreas and the common bile duct and reached the gallbladder caudad to the cystic duct It crossed the latter anteriorly and supplied the peritoneal surface of the gallbladder The deep cystic in this case was typical i e it arose from the right hepatic in Calot s triangle

Type X A direct origin of the cystic from the superior pancreaticoduodenal was encountered in one subject (Plate VI No 105 Daseler et al 1 case Flint 1 case) Since the retroduodenal in the author s case arose from the superior

pancreaticoduodenal and gave rise to the cystic the pattern was regarded as an origin of the cystic from the retroduodenal into which classification it was accordingly included (type VI)

Type XI Origin of the cystic artery as a direct branch of the aorta as reported by Lipshutz in 2 cases and by Belou in 1 case with double cystics was not observed by the author of this book nor by Daseler et al

Type XII An origin of the cystic from the right gastro epiploic was reported by Kosinski (1 case) Neither the author nor Daseler et al nor Belou observed such an origin

Various Types of Double Cystic Arteries

The Cysticae gemellae of Vesalius (1561)

In view of their surgical importance variations of dual cystics are well worth recording Patterns comprise the following types

1 Two cystics from the right hepatic (22 cases) Flint 16 Susloff 9 Lipshutz 5 Thompson 3 Brewer 3 Daseler Anson Hambley and Reimann 57 cases in 500 Belou 8 cases in 150

Variations of the double cystic in Calot s triangle which the author observed comprised (1) both cystics from the right hepatic (Plate V No 84) (2) each cystic from a separate branch of the right hepatic (*Plate V Nos 88 89*) (3) the deep cystic remaining in the triangle the superficial leaving it by swinging around the cystic duct (Plate V No 83) (4) the superficial and the deep cystics criss crossing in the triangle (Plate V No 99) (5) the superficial cystic anastomosed with a branch from the left hepatic (Plate VI No 110)

2 Two cystics from a replaced right hepatic derived from the superior mesenteric (5 cases *Plate V No 85*) *Belou 2* cases Lipshutz 2 cases Daseler et al 14

3 One cystic from the right hepatic in the triangle the other from the right hepatic to the left of the hepatic duct which it crosses anteriorly (8 cases Plate V No 90) Daseler et al 1 case

4 One cystic from an accessory right hepatic from the superior mesenteric the other from the right hepatic (Daseler et al 2 cases) or from the right hepatic to the left of the hepatic duct (one of the author s cases Plate V No 92)

5 One cystic from a replaced right hepatic from the superior mesenteric the other from the middle hepatic (1 case *Plate V No 93*) or *the left hepatic* Belou 1 case

6 Two cystics from the right hepatic to the left of the hepatic duct both crossing the latter anteriorly (1 case *Plate V No 97*)

7 One cystic from the right hepatic the other from the left or the middle hepatic (2 cases Plate V *No 91*) Belou 2 cases Lipshutz 1 case *Susloff 3* Flint 3 Thompson 1 McWhorter 1, Daseler et al 3

8 One cystic from the right hepatic the other from the common hepatic (1 case Plate IV No 68) Susloff 1 case Thompson 3 Daseler et al *4*

9 One cystic from the left hepatic the other from the gastroduodenal Daseler et al 1 case

10 One cystic from the right hepatic to the left of the hepatic duct the other *from the gastroduodenal (1 case Plate* VI No 107)

11 One cystic from the right hepatic the other from the gastroduodenal or its retroduodenal branch (5 cases Plate VI No 104) Flint 11 cases Brewer 5 Rossi and Cova 5 Belou 3 Thompson 1 Daseler et al 6

12 Two cystics from the gastroduodenal McWhorter 1 case

13 One cystic from the right hepatic *in the triangle the other from a branch* of the right hepatic to the fissured area under the gallbladder (1 case Plate III No 57)

14 Dual cystic arteries at the point of origin but fused distally to form a common trunk (2 cases Plate VI Nos 109 110) Daseler et al 1 case

15 Triple cystic arteries from the right hepatic (1 case Plate V No 81) Daseler et al 1 Brewer 1 Browne 1

16 One cystic from the right hepatic the other directly from the aorta Lipshutz 2 cases Belou 1 case

17 One cystic from the right hepatic the other from the superior mesenteric (one of the author s cases Plate VI No 108) Belou 2 cases

18 Two cystics from the common hepatic

19 Two cystics from the superior mesenteric

20 Two cystics from the aorta

As far as the author knows the last three patterns have never been observed nor has anyone recorded two cystics derived from an artery or arteries arising to the left of the aorta

Belou s Pioneer Investigations on the Cystic and the Hepatic Arteries

In order that anatomists and surgeons readily may become acquainted with Belou s excellent work on the cystic artery the following summary thereof has been made by the author After a dissection of the biliary region in 80 bodies Belou of Buenos Aires (1915) reported that the cystic duct has the following arterial relations

1 Along its superior left side it was related to one cystic artery (72 per cent) or with two cystic arteries (14 per cent)

2 Its posterior surface was related to one branch of a bifurcating right hepatic (5 cases) or to two branches thereof (1 case)

3 Its inferior right surface was related to a branch of the gastroduodenal the arteria cystica inferior (6 per cent)

4 Its posterior surface was related to the hepatic artery proper (4 per cent)

5 Its anterior or inferior surface was entirely related to a cystic stemming from the superior mesenteric or the aorta (4 cases)

Later Belou augmented the number of his investigations to 150 bodies noting that in this sample dual cystics occurred in 19 per cent Of the dual cystics one was termed the arteria cystica superior or left cystic the other the arteria cystica inferior or right cystic The right hepatic had a retrobiliary course in 71 per cent and a prebiliary one in 14 per cent It crossed the inferior segment of the hepatic duct in 20 per cent its middle segment in 54 per cent and its superior segment in 14 per cent A common hepatic arose from the superior mesenteric in 6 per cent (8 cases) A right hepatic stemmed from the superior mesenteric in 9 per cent While Belou did not give a statistical analysis of the constituents of the celiac axis or of aberrant hepatic arteries he encountered and depicted instances of an accessory left hepatic from the left gastric with a cystic therefrom and the arteria hepatica media of Haller which in his estimate occurred only in 2 per cent whereas actually it is always present in most instances being a branch of either the right hepatic or the left hepatic The blood supply to the quadrate and the caudate lobes was not investigated nor was the blood supply of the upper abdominal organs considered as a whole

The site and the point of origin of the single cystic artery (81 per cent as observed in 150 bodies) described and illustrated by Belou comprised the following types

1 In the cystic triangle from a normal right hepatic (30 per cent 46 cases) or from an abnormal right hepatic stemming from the superior mesenteric (11 per cent)

2 In the triangle as a branch of the normal right hepatic that crossed in front of the hepatic duct (7 33 per cent 11 cases)

3 In the triangle from one of the *terminal branches of a normal right hepatic* that passed behind the hepatic duct (6 per cent 8 cases)

4 From the gastroduodenal (4 per cent 6 cases)

5 From a normal or an abnormal hepatic trunk (4 66 per cent 7 cases) the cystic crossing the hepatic duct anteriorly or posteriorly

6 From a right hepatic coursing to the left of the hepatic duct which it crosses anteriorly (2 per cent 3 cases)

7 From a normal right hepatic that passed behind the hepatic duct the site of origin of the cystic being to the left of the hepatic duct which it crosses anteriorly (4 per cent 6 cases)

8 In the triangle as an *actual terminal branch* of the right hepatic the latter *having passed behind the hepatic duct* (2 per cent 3 cases)

9 *In the triangle from the upper or* left branch of the two branches of a right hepatic that passed behind the hepatic duct (1 33 per cent 2 cases)

10 From a terminal branch of the right hepatic the latter having crossed the hepatic duct anteriorly (1 33 per cent 2 cases)

11 From a normal left hepatic the cystic crossing the latter anteriorly (1 33 per cent 2 cases)

12 From the *middle hepatic* artery (1 case)

Sites and points of origin of the dual cystic arteries (10 per cent in 150 bodies) comprised the following types

1 Two cystics arise in the cystic triangle from the trunk or the terminal branches of a normal right hepatic that passed behind the hepatic duct (5 33 per cent 8 cases) Of this type there were three variants (a) the dual cystics arise in the *triangle from a normal right hepatic* (3 cases) (b) the two cystics arise in the triangle from a right hepatic derived from the superior mesenteric (2 cases) (c) the two cystics arise in the triangle from the right hepatic branch of a *hepatic trunk derived from the* superior mesenteric (1 case)

2 *One cystic (superior) arises in the* triangle from a normal right hepatic the other *(inferior) from the gastroduodenal* (2 per cent 3 cases)

3 One cystic arises *in the triangle* from the right hepatic the other from the left hepatic to the left of the hepatic duct which it crosses anteriorly (2 per cent 3 cases) Among these was a case in which one cystic was a branch of an abnormal left hepatic the other a branch of an abnormal right hepatic in the triangle

4 The two cystics arise in the triangle from a right hepatic that passed in front of the hepatic duct (2 cases)

Belou found the blood supply of the *biliary tract to vary to such an extent* that no uniform pattern can be presented *As a general rule the upper part* of the bile tract is supplied by the right hepatic the lower by the gastroduodenal or the superior mesenteric, the two regions often being anastomosed by one or more rami

The epiploic (omental) section of the bile duct is supplied by (a) A ramus of the right hepatic which divides into an ascending branch that gradually peters out upward and a descending *ramus that supplies the entire epiploic* segment and ultimately anastomoses *with an ascending ramus of the gastro* duodenal (b) Various rami stemming from a left terminal branch of the right hepatic the right hepatic or the ascending hepatic Occasionally some rami take origin directly from the cystic (c) A descending ramus known as the *arteriole of the cystic duct*, which arises from the cystic at the neck region of the *gallbladder and which runs* along the cystic duct to its junction point with the hepatic duct where it divides into an ascending and a descending branch the former at times anastomoses with

biliary branches of the right hepatic the latter with ascending branches of the gastroduodenal or the posterior superior pancreaticoduodenal (author's retroduodenal)

The retroduodenal segment of the common duct is supplied by one or various rami derived from the gastroduodenal or the posterior superior pancreaticoduodenal The latter may give off an ascending branch that frequently anastomoses with a hepatic branch or with the cystic as it courses along the anterior surface of the common duct Sometimes the segment is supplied by branches derived from an abnormal hepatic (hepatomesenteric artery) or from rami stemming from an inferior cystic (superficial cystic) derived from the gastroduodenal or the posterior superior pancreaticoduodenal

Both the retroduodenal and the parietal segments of the common duct are supplied by arteries and veins derived from the posterior pancreaticoduodenal arcades When the arcades are situated to the right of the common duct duodenal rami as they cross the duct supply branches to it When however the arcades cross the common duct the choledochal rami take origin directly from the arc and are much shorter Belou emphasizes the point that not all arteries having an intimate relation with the bile duct system assist in its blood supply Thus a superior choledochal artery stemming from the right hepatic may accompany the bile duct in its entire course without aiding in its vascularization the supply in this case coming from an inferior choledochal artery derived from the pancreaticoduodenal or the gastroduodenal

Most commonly the cystic duct is supplied by the cystic artery or by the right hepatic less frequently by a ramus of the right hepatic that enters the liver It may receive one or more rami which stem from various cystic rami When the artery of the cystic duct stems from the cystic artery it may arise at the neck of the gallbladder and take a recurrent course running parallel with the cystic duct to its junction point with the hepatic duct or it may take origin from the cystic before the latter reaches the vesicle dividing into an ascending ramus directed toward the gallbladder and into a descending ramus coursing to the confluence of the bile ducts A similar disposition was seen when the cystic duct artery was a ramus of the right hepatic or of one of its liver branches

Finally when the cystic artery is derived from the superior mesenteric the gastroduodenal or the pancreaticoduodenal it contributes to the blood supply of the entire biliary tract giving off branches at different levels along its course Belou concludes his classical work thus

En resumen la arteria cistica irriga por sus ramas la vesicula biliar los bordes marginales de los lobulos limitantes cuadrado y derecho así como la substancia hepatica marginal de la foseta biliar y la que linda con la foseta de los lóbulos cuadrado y derecho Por intermedio de una rama colateral irriga en menos de la mitad de los casos parte o todo el conducto cistico y a veces parte del conducto hepato colédoco

The topic of the hepatic and the cystic arteries may well be concluded by recalling what Haller over 200 years ago (1745) said about them to wit

Hepatica adeo ante truncum venae portarum pergit e ei fere parallela deinde duobus fere truncis ut Eustachius ubique pingit alias tamen tribus et quatuor hepati inferitur ad fossam umbialem et fossam ductus venosi divisus

Cystica arteria oritur longe plerumque unica etsi duas numeret Winslow Vesalius Ea dextrorsum ad cervicem vesiculae exit duobusque ramis eam amplectitur anteriori evidente et inferiori profundo Vide duas unam a dextra hepatica ortam alteram a sinisteriore

The diseases of the gall bladder belong to the surgeon and only through him can speedy and permanent relief be obtained

—JUSTUS OHAGE *Medical News* 1887

Today the surgical borderland lies in the upper region of the abdomen a locality until recently considered almost purely medical

—WILLIAM JAMES MAYO 1901

6

The Gallbladder, the Biliary Ducts and Their Arterial Relations

Pioneer Work of the Mayo Brothers

The words of one of the introductory quotations were spoken by William James Mayo of Minnesota in his famous oration on surgery The Association of *Surgical Lesions in the Upper Abdomen* [1] in which he began his hard pioneer struggle for the diagnosis of gall stones and the surgical treatment of diseases of the gallbladder and the bile ducts In his struggle he was ably assisted by his brother Charles who in speaking of indigestion or dyspepsia said that

treatment directed to the stomach in these cases is about as effectual as it would be to deluge a fire alarm box with water because it is sounding the alarm of the fire " (Clapesattle The Doctors Mayo p 422 Univ Minn Press 1941)

Charles Mayo will long be remembered for his highly descriptive phrase When the hatchet sharp edge of the liver is gone you had better take out the gallbladder (cited from Clapesattle)

The words of the other caption are those of Justus Ohage[3] spoken before the Ramsey County Medical Society St Paul Minnesota shortly after he had performed the first cholecystectomy in America (September 24 1886) the patient being a woman aged 35 On many occasions Ohage graciously permitted the young Mayo brothers to watch him operate they having been sent to him by their father Dr William Worrell Mayo of Rochester

As stated by Clapesattle in her biography of the Mayo brothers (University of Minnesota Press 1941)

It had taken the Mayos twelve years to accumulate their first five hundred operations on the gallbladder and ducts but their second five hundred came in eighteen months and in December 1901 Dr Charlie read to the Southern Surgical Association his and his brother s joint report of one thousand operations for gallbladder disease

In this review of their thousand gall

1 Trans Western Surg Assoc Collections of Papers Previous to 1909 1 231–43

2 Karl Langenbuch (1846–1901) of Kiel Germany chief of the Lazarus Krankenhaus in Berlin was the first to remove the gallbladder in cholelithiasis on July 15 1882 (*Berl klin Wchnschr* 19 725 1882) Later he made a successful resection of a large part of the liver (Schnurleber *ibid* 25 37 1888) John Stough Bobbs of Indianapolis is usually cited as the first American surgeon to have opened the gallbladder for stones (June 15 1867) The operation cholecystotomy was so named by James Marion Sims who introduced it on April 18 1878 and gave a classical description of it The first cholecystectomy in America was performed by Justus Ohage in St Joseph s Hospital St Paul Minnesota on September 24 1886 At the time it was the ninth that had been performed in the world

3 Reported in The Surgical Treatment of Diseases of the Gall bladder *Medical News* February 19 and 26 1887 on pages 1–24

bladder operations the Mayo brothers made an unequivocal statement of the basis on which they reckoned mortality from operation. They took the position of the layman: If the patient goes into the hospital alive and comes out dead, the death should be charged to the operation no matter how many months have elapsed or what other disorders have developed to be the actual cause of death. (Clapesattle: The Doctors Mayo, p. 182, Univ. Minn. Press, 1941.)

That was hard on the statistics.

A percentage of the deaths could be fairly excluded, but since our object is to show the relative curability of gallstone disease rather than good statistics, we have adopted this method as it is at least unprejudiced. Even so, their mortality for the entire series, including the operations done in the years of inexperience, was only five per cent, and for cases of simple gallstones it was just above two per cent.[4]

To these introductory remarks should be appended, in tribute to his incessant plea for dexterity in biliary surgery, the words of the late Dr. Lahey of the Lahey Clinic in Boston:

We should publicize the fact that cholecystectomy is a dangerous operation. It is dangerous unless one realizes how important it is to control the blood supply, to demonstrate definitely the anatomic relationships, and to realize that anomalous anatomy is very common. I believe we could do nothing better than to write more and more on the need for accuracy in cholecystectomy and recording the findings of the common duct in the pancreas and behind the duodenum. (*Ann. Surg.* 129:763, 1948.)

A reading of the description by Cole, Reynolds and Ireneus (1949) of 53 cases in which stricture of the choledochus had developed following imperfect technic at cholecystectomy and a study of the reasons for an electrosurgical obliteration of the gallbladder as devised and introduced by Max Thorek (1950) to avoid injury to the bile ducts and the arteries are convincing attestations of the difficulty and the seriousness of cholecystic surgery. While speaking on the latter topic Ravdin (1952) revealed the fact that during the past 5 years 31 patients had been sent to him for operation because of operatively induced defects of the common duct. His comment to this was: "It merely means that while most surgeons teach that cholecystic surgery is easy, it is difficult."

The same attitude was taken by Walters and Philipps of the Mayo Clinic (1949) in their editorial entitled "The Increasing Frequency of Injuries of the Common Bile Duct and Hepatic Duct." Of 165 patients operated upon by Walters for stricture of the common duct, all but two had previously undergone an operation of the biliary tract during which the bile duct was injured with resultant stricture. One operation for the repair of stricture of the bile duct as carried out by Walters produced satisfactory results in 60 per cent of the cases. The authors presented the following admonition:

A thorough knowledge of the anatomy of the biliary tract, including the anomalies which may be found, accurate exposure and lighting of the operative field are absolute necessities for safe biliary surgery. In the absence of these factors serious injuries of the common bile duct, the hepatic artery and its main branches and the portal vein may easily occur. (*Surg.* 25:169, 1949.)

Anomalies of the Gallbladder

Major anomalous conditions of the gallbladder observed by the author in 500 bodies studied for this purpose comprise only 4 cases, to wit: (a) the gallbladder was transposed, i.e., was located in the fossa of the umbilical vein instead of in its normal bed; (b) a variation of this condition, in which the umbilical

[4] In his text *Modern Surgery*, John Chalmers DaCosta cites a personal communication from the Mayo Brothers to the effect that at the Mayo Clinic from Jan. 1, 1907 to Jan. 1, 1918 there were 5,665 operations for gallstones with a mortality of 2.4 per cent. In 1908 Hans Kehr of Germany had reported a mortality of 2 per cent.

fossa and the ligamentum teres were transposed *to the right of the gallbladder*, the latter being normal in position (Fig 80); (c) the gallbladder was hidden behind the duodenum and the transverse colon to such an extent that on opening the abdomen there appeared to be a case of congenital absence of the gallbladder, but dissection of the hepatocystocolic ligament revealed its low displacement (Fig 13); (d) a case of complete situs inversus in which the gallbladder and the liver (both otherwise normal) were transposed to the left side, it being the only case observed by the author in 1 500 dissections (Fig 91); (e) as a fifth anomaly may be listed a case of an apparent double gallbladder (only 28 reported in *the literature*, Gross *1936*) observed in 1952 in a newborn infant but as yet not dissected for accurate evaluation as to anatomic structures and blood supply (*Fig* 152).

Common variations of the pear shaped gallbladder observed by the author comprised variations in form, in dimensions (length 6 to 10 cm, width 2 to 4 cm) and in extent of projection of the fundus beyond the anterior border of the liver, in the folding of the fundus within its peritoneal coat, in sacculation at the neck (pouch of Hartmann and extent of this free portion), in the manner of attachment to the stomach, the duodenum and the transverse colon by peri*toneal bands (ligaments)* and *in the* mode of attachment to the liver, the organ frequently being suspended by a mesentery several centimeters wide and of various length. When pathologic conditions of the gallbladder existed, the specimen was dissected but not used for statistical estimate except in one instance to show the enormous enlargement which a biliary obstruction may produce in the biliary tract, especially in the hepatic duct (Fig 99). Two cases in which the gallbladder had been removed at some time during life (as revealed when the abdomen was opened) were *used to illustrate* remnants of the cystic artery and of the stump of the cystic duct (Figs 92, 93).

Variations of the biliary ducts as observed *in the author's dissections* are discussed under separate headings and are illustrated in many of his figures. They occurred with such frequency and were of such pronounced character as to be of vital concern to every surgeon. A disregard of the anomalies, especially of the accessory hepatic ducts, courts injury of them with resultant disconcerting postoperative leakage of bile. That the majority of benign strictures of the common duct are due to surgical injury during cholecystectomy has been well known since the days of the Mayo brothers and recently has been emphasized again by Lahey, Wilson and Gillespie, Ravdin, Cole, Walters and Phillipps, *Moosman and Coller* (1951) and many others.

The Hepatic Duct

The hepatic duct varies in length from 2 to 7 cm, the average length being 4 cm. Variations in diameter (4 mm average) are frequent, an irregular bulge resembling the embryonic antrum of Boyden often being present near *the* region where the cystic duct joins it to form the common bile duct. Early or late confluence of the extrahepatic bile *tributaries to form* the hepatic duct is the factor determining whether branching of the hepatic duct into its main right and left branches takes place at a high point (i e, within the portal fissure) or at a low point (i e, outside the fissure). Union of the right and the left branches of the hepatic duct usually occurs high in the portal fissure but may be retarded, *giving rise to a short* low forked hepatic duct. Through this fork, under or over it, the right hepatic or the cystic artery may pass (Plate IV, No 77). The situation may be the reverse

of this (high forked hepatic duct) with similar relation of the two arteries (Plate IV, No 76) The right and the left limbs of the hepatic duct may be extremely short even intrahepatic the hepatic duct then emerging directly from the liver As will be shown shortly the majority of accessory hepatic ducts are but aberrantly placed biliary ducts i e they join the hepatic duct or its right branch in a late manner

In about 85 per cent of subjects the right hepatic artery crosses the hepatic duct anteriorly at its midpoint However the right hepatic may be represented by two branches both crossing it ventrally or dorsally or one crossing it ventrally the other dorsally (Plate I No 12 Plate II No 10) When a cystic artery arises from the middle hepatic or the left hepatic as a rule it crosses it anteriorly as it does when it arises from the right hepatic to the left of the hepatic duct Occasionally the cystic takes origin from the right hepatic behind the hepatic duct

The mode of formation of the hepatic duct by the extrahepatic bile ducts varies to such an extent that no two patterns are ever exactly the same This conclusion is based on an investigation (made under the author s supervision by Schroy for his M A thesis at the Daniel Baugh Institute of Anatomy) of 50 specimens in which the hepatic duct and its tributaries were injected with a plastic material (a 28 per cent solution of vinyl acetate in acetone) and in which after hardening of the plastic material the tributaries were dissected up to their very exit from the liver Later Healey and Schroy studied the mode of formation of the hepatic duct and the anatomy of the bile ducts inside the liver in 100 plastic corrosion casts Schroy having selected this topic as his doctorate (Ph D) thesis A detailed description of their findings is given in Chapter 7 for the present the following items from their work may be noted (Fig 6)

Typically the hepatic duct divides into a right and a left hepatic duct The right hepatic duct (like the right hepatic artery) usually divides into an anterior (ventral) and a posterior (dorsal) segment duct the latter draining that portion of the right lobe related to the visceral surface of the liver the former draining the remainder of the right lobe The left hepatic duct (like the left hepatic artery) likewise divides into two main branches a medial segment duct and a lateral segment duct The medial segment duct drains the quadrate lobe and in its course and distribution is comparable with the middle hepatic artery The lateral segment duct drains that portion of the liver which is usually referred to as the left lobe in the gross descriptions of this organ In many instances (27 cases in 100) there are two main ducts coming from the right lobe i e the anterior and the posterior segment ducts do not join to form a right hepatic duct but join the hepatic duct separately the lower in some instances being sufficiently low as to constitute what is commonly called an accessory hepatic duct Similarly, on the left side the medial and the lateral segment ducts may have a separate course with separate openings occurring rarely (2 cases in 100)

The medial segment duct is a branch from the left hepatic duct and occasionally may drain into one of the branches of the lateral segment duct—in its course in the umbilical fossa it typically receives four tributaries from the quadrate lobe and in some instances tributaries from the lateral segment

While the quadrate lobe is drained mainly by the medial segment duct the caudate lobe usually is drained by *both* the right and the left hepatic ducts Patterns vary Commonly three ducts drain this lobe to wit the caudate proc

ess is drained by a duct which joins the right hepatic duct the left portion of the caudate lobe proper by a duct which joins the left hepatic duct and the right portion of the *caudate lobe proper by a* duct which may enter with about equal frequency into either the right or the left hepatic duct

The Cystic Duct

The cystic duct averages about 4 cm in length and 3 mm in width The range of variation in length extends from 1 to 8 cm The mode of union of the cystic duct with the hepatic duct presents the well known angular parallel and *spiral types (Plate II Nos 22 23 26)* The angular union (high low or intermediate in position) is effected by a short (1 cm) a medium (3 cm) or a long (6 cm) cystic duct which at times *is slightly* crooked upward or downward at its beginning In the parallel type the cystic duct is bound in most instances laterally or posteriorly to the hepatic duct by connective tissue for a short distance (1 to 5 cm) constituting short parallels (Plate II No 36) or for a long distance (above 5 cm) rendering long parallels (Plate II No 31) In the spiral type the cystic duct pursues a spiral course anterior or posterior to the hepatic duct and opens into it after a *one quarter a three quarter or a full* spiral twist has been made The one half spiral to the left is fairly common and may be short or long (Plate II No 30 Plate VI No 105)

Although in most instances the cystic duct opens to the right of the hepatic duct there are sufficient cases where the cystic duct joins the hepatic duct anteriorly posteriorly or to the left (Plate IV No 69) to warrant the statement that the cystic duct may open anywhere along the course of the hepatic duct It may open into a huge right accessory hepatic duct as instanced in 2 cases where the anterior and the posterior segment ducts of the right lobe did not unite to form a right hepatic duct the posterior segment duct receiving the cystic duct (Fig 58) An accessory *hepatic duct is often dangerously close to* the cystic duct As will be shown shortly it may cross it in a caudad direction or run parallel with it (Plate III No 41)

The Common Bile Duct

The common bile duct averages about 7 to 9 cm in length and 6 mm in width In its descent to the duodenum it presents the following segments

1 The supraduodenal or first portion lies above the duodenum and in its descent between the two layers of the lesser omentum (hepatoduodenal ligament) in front of the foramen of Winslow measures about 3 to 4 cm in length It is crossed anteriorly by the retroduodenal artery which with few exceptions is the first branch of the gastroduodenal

2 The retroduodenal or second portion lies behind the first part of the duodenum to which it may be attached partially

3 The intrapancreatic or third portion lies behind the head of the pancreas In about one third of the cases respectively considered it may be entirely intrapancreatic entirely extrapancreatic or partially intrapancreatic (Sterling 1949) *It is often tapered* like a funnel and deflected to the right this being the proximal extraduodenal part of the double S shaped curve made distally by the common duct The lumen of the duct in this area averages 6 3 mm in diameter (Sterling) See Smanio page 63

4 The intra (trans) duodenal or intramural portion (pars intestinalis) has many freely movable valvules It passes for 1 to 2 cm obliquely through the posterior medial wall of the descending duodenum below its middle where in most instances it is joined by the pancreatic duct from the left The two ducts form an expanded common canal

(ampulla of Vater?) that opens into the duodenum via the major duodenal papilla situated 8 to 10 cm from the pylorus The papilla at times is very low allowing at least an anatomic approach to it from the infracolic region

Variations are manifold the most striking being many instances in which the two ducts open separately on the duodenal papilla cases in which union of the two ducts takes place outside the duodenal wall and cases in which the ampulla of Vater is small or entirely lacking According to Sterling the trans duodenal portion of the common duct has a thicker wall and its lumen is smaller than that of the extraduodenal portion In an examination of 80 dis sections Sterling found absolutely no evidence of the existence of an ampulla of Vater and for this reason proposes that the term ampulla be deleted and that the term papilla of Vater be used to designate the expanded distal part of the common bile duct In his material the papilla averaged 11 1 mm in length and 3 4 mm in thickness in 64 per cent showing separate openings for the pan creatic and the common bile ducts

Union of the Cystic Duct with the Hepatic Duct What seemingly is the common bile duct is often not the com mon bile duct but the hepatic duct intimately and firmly united by dense connective tissue to the cystic duct con stituting as already outlined the short and the long parallel cystic ducts The length of the common bile duct depends not only on the markedly varied topo graphic position and the different form of the duodenum but also in a large measure on the site of opening of the cystic duct into the hepatic duct which incidentally occurs anywhere along the duct often on its anterior aspect In cases where the union of the two ducts has been prolonged to the level of the duodenum (6 cm) or to a point just above or below it (Plate I No 5 Plate III No 57 Plate V No 86) there is either no supraduodenal portion of the common bile duct or very little of it Such long veiled and hidden cystic ducts may harbor residual gallstones after the main free part of the cystic duct has been removed Because of the parallel posi tion the spiral course and the bound condition of the cystic duct the common hepatic duct and to a lesser extent the common bile duct (Lahey) have often been injured Management of the benign strictures of the common duct following such injury recently has been outlined by Wilson and Gillespie

Arterial Relations to the Common Bile Duct The hepatic and the gastro duodenal in most instances are entirely to the left of the common bile duct They may cross its supraduodenal part anteriorly as is always the case with the retroduodenal artery which will be de scribed separately Relations of the right hepatic to the common bile duct vary considerably for the artery may course to its right to its left anterior or pos terior to it Just as the right hepatic may present a caterpillarlike loop and twists inside and outside the cystic tri angle so in some instances a loop for mation of it may overlie the junction point of the cystic duct with the hepatic duct (Plate II No 29) Aberrant right hepatics from the superior mesenteric in their ascent to the cystic triangle often are intimately related to and even in contact with the common bile duct for a considerable distance before or after crossing it (Plate III No 45) The lymph node of Luschka in many in stances complicates matters by the fact that it is large and is wrapped around the common duct thus obstructing dis cernment of an ascending aberrant right hepatic (Fig 56) Heavy cordlike strands of autonomic nerve fibers to the gall bladder the nature of which is clamor ing for investigation may further com plicate precise delineation of structures

Aberrant (Accessory) Hepatic Ducts

From the regional arrangement of the extrahepatic bile ducts previously described and from the courses they take to become the common hepatic duct, it is extremely difficult to define an accessory hepatic duct, for ultimately every accessory hepatic duct, whether right or left, represents but an aberrantly placed tributary to the common hepatic duct, to its main right and left branches, to the common bile duct or to the cystic duct. When the two main segmental ducts (anterior and posterior) of the right lobe do not unite to form a right hepatic duct (28 per cent, Healey and Schroy) the posterior segmental duct may be sufficiently low to receive the cystic duct, 4 cases of which were observed in 250 bodies (Fig. 58). After the common hepatic duct has divided into its main right and left branches any of the extrahepatic bile ducts may course caudad to the division point of the common hepatic duct to join it or its right or left branch. In doing so the duct on the right side may course through the confines of the cystic triangle of Calot, where it commonly is regarded as an accessory hepatic duct. (See page 117.)

The striking discrepancies in the literature regarding the percentage incidence of accessory hepatic ducts (2 to 28 per cent) are due to the diversified interpretation on the part of authors as to what constitutes an accessory hepatic duct. The viewpoint that accessory hepatic ducts do not occur on the left side is erroneous. Because of their relative insignificance in biliary surgery they have not been emphasized and because of the absence of a cystic duct and therefore of a cystic triangle on the left side they are less numeous (Fig. 85).

An accessory hepatic artery (from the left gastric, superior mesenteric) is accessory only in origin, for, as shown by Healey and Schroy in plastic casts, every accessory hepatic supplies from other sources the blood volume mass necessary for a specific region of the liver not supplied through the celiac hepatics. The term accessory hepatic duct is likewise misleading for, having the same origin from the liver, each so-called accessory hepatic duct is but a tributary to the biliary tree. The term aberrant hepatic duct would be more appropriate, but in view of common usage the old term accessory hepatic duct will be retained. While any standard established by an author is purely arbitrary, in the following account (covering 200 bodies) accessory hepatic ducts will be regarded as extrahepatic bile tributaries that join the common bile duct, the cystic duct, the hepatic duct or its right or left branch in sites where they are prone to be injured in biliary surgery.

Surgically considered, accessory hepatic ducts should always be handled with care. Their incidence is far greater than generally appreciated, having been observed in 18 per cent (36 cases in 200 bodies). In 10 per cent they joined the hepatic duct (Plate III, No. 51), in 3.5 per cent the right branch of the hepatic duct (Plate III, No. 41) and in 1 per cent the common bile duct (Plate II, No. 35; Plate III, No. 16). In 2 per cent the cystic duct drained into an accessory hepatic duct which joined the common hepatic duct (Plate III, No. 55). In one instance two accessory hepatic ducts joined the hepatic duct (Plate IV, No. 72). In another case one accessory joined the right branch of the hepatic duct, the other the hepatic duct (Plate III, No. 41). There were only two cases of an accessory hepatic duct arising from the left side—one in which it came from the caudate lobe and joined the hepatic duct (Plate V, No. 86), the other in which it joined the common bile duct, the deep cystic artery passing between it and the hepatic duct (Plate III, No. 46). Accessory hepatic ducts joining the right branch of the hepatic

duct (Plate I, No 10) are usually sufficiently high not to be in a position of surgical harm, but those joining the cystic duct (Plate III No 55) or running parallel with it (Plate III No 41) or crossing it in a caudal direction (Plate II No 35) decidedly are

Subvesicular Ducts Surgically important is the fact that in many instances (35 per cent Healey and Schroy) an accessory duct arises (Plate VI No 101) or courses under the gallbladder mostly to its lateral side (Plate IV No 71) These subvesicular ducts are often filamentous and therefore hard to detect Largely restricted to the gallbladder bed because of their small caliber they may be mistaken for dense strands of fibrous tissue or nerves and accordingly can be torn or severed readily during cholecystectomy causing disconcerting postoperative jaundice Usually the subvesicular ducts drain into the anterior segment duct or into the right hepatic duct (Figs 59 71 77) In contrast with other bile ducts inside the liver they are not accompanied by a branch of the portal vein but occasionally are accompanied by an artery (5 per cent Healey et al)

Arterial Relations of Accessory Hepatic Ducts These are often surgically dangerous and difficult to analyze The course of the right hepatic may be above (Plate III No 55) or below the accessory hepatic duct (Plate II No 22) it may be looped around it (Plate I No 8) or be both below and above it (Plate I No 16) One branch of the right hepatic may be below the other above it (Plate V No 89) An aberrant right hepatic from the superior mesenteric may cross it (Plate III No 48) two branches of the right hepatics with two cystics may be above it (Plate V No 82) the right hepatic may cross between two accessory hepatic ducts (Plate III No 41 Plate IV No 72)

The cystic artery itself often has a comparable close relation to the accessory hepatic duct The cystic may cross anterior or posterior to it (Plate III No 51) may arise below (Plate I No 8) or above it (Plate I No 16) With two cystics one may be below the other above it (Plate V No 89) or both may be above it (Plate V No 82) In short an accessory hepatic duct may traverse any part of the cystic triangle as may the cystic artery Very odd were two cases one in which the right hepatic passed through a split hepatic duct (actually a case of an anastomosis of an accessory hepatic duct from the hepatic duct to the common bile duct the artery being at first ventral then dorsal to the hepatic duct (Plate II No 35) and the case in which the deep cystic artery passed between a left accessory hepatic duct and the hepatic duct (Plate III No 16 Figs 98 85)

Relations of the Right Hepatic and Its Branches Especially of the Cystics to the Bile Ducts

These relations depend on the origin the mode of branching (early or late) and the course taken by the right hepatic When the cystic artery arises from an artery other than the right hepatic (middle hepatic left hepatic hepatic gastroduodenal) one biliary relation is outstanding—it must cross the bile duct system to reach the gallbladder as it does when it arises from the right hepatic before the latter has crossed the hepatic duct (Plate IV Nos 70–74) In the cystic triangle a right hepatic of celiac or aortic origin may be high low or intermediate in position (Plate I Nos 20 3 14) depending on where it crossed the hepatic duct and where it courses in the triangle For the most part the common hepatic artery lies entirely to the left of the common bile duct However arterial relations to the latter become very propinquous with aberrant right hepatics arising from the superior mes

enteric for as stated previously in their ascent to the cystic triangle they cross not only the common bile duct but also frequently the cystic duct as well (Figs 15 36 42 85 89) An aberrant right hepatic proceeds upward, ventral or dorsal to the portal vein prevailingly dorsal (Figs 12 88 15 89) as is the case when it arises separately, i e independently of the left hepatic from the celiac (Fig 83)

In the majority of cases the celiacal *right hepatic crosses the hepatic duct posteriorly* purely ventral crossings have been observed in only 12 per cent (Figs 11 21 52 53)

When union of the right and the left branches of the hepatic duct is retarded a low forked hepatic duct is formed Through this fork the right hepatic may pass giving off the cystic as it crosses (Plate IV No 77) The situation can be the reverse of this (high forked hepatic duct) with similar relations of the two arteries (Plate IV No 76)

The right hepatic not infrequently is represented by two branches both crossing the hepatic duct anteriorly posteriorly or one crossing it anteriorly the other posteriorly (Plate IV Nos 71 75 Plate I No 12) In the cystic triangle the right hepatic may divide into two major branches each giving off a cystic (superficial and deep) (Plate V No 88) A comparable division of the right hepatic may take place to the left of the hepatic duct thus necessitating a crossing of the latter by the two branches Such two right hepatics are not to be confused with cases in which there are actually two right hepatics one arising from the celiac the other an accessory derived from the superior mesenteric (Plate III No 49) the blood supply to the anterior and the posterior segments of the right lobe in such instances coming from two different sources The two right hepatics occasionally anastomose in the cystic triangle (Plate II No 38)

Even after a high crossing of the hepatic duct or a high course to its left the right hepatic often descends in the cystic triangle to a region which surgically considered is dangerously close to the cystic duct (Plate II Nos 26 28) The same surgical hazard is brought about by *the right hepatic when it traverses* the hepatic duct at a low level or upper part of the common bile duct at a high level this being especially the case when the right hepatic is of the aberrant type (*Plate III Nos 46–50*)

Replacement of the right hepatic from the celiac or from the aorta does not materially alter the relational anatomy of Calot s triangle as far as origin of the cystic artery is concerned but replacement of the right hepatic from the superior mesenteric does so decidedly A replaced right hepatic from the superior mesenteric usually gives off the cystic either single or double (Plate III No 47 Plate V No 85) but an accessory hepatic from this source may or may not (Plate III Nos 52, 49) Every sample requires inspection and careful analysis for an aberrant right hepatic from the superior mesenteric in its ascent to the cystic triangle crosses not only the common bile duct but also frequently the cystic duct as well (Plate II No 38 Plate III Nos 45 47)

Caterpillarlike Loop of the Right Hepatic

Both inside and outside the cystic triangle the right hepatic often makes a characteristic caterpillar like loop (hump) convexity of which points downward upward to the right or to the left (Plate II Nos 24 37 22 32) Odd indeed was the case in which the entire hepatic swung into Calot s triangle and after giving rise to the right hepatic with dual cystics from a loop formation left the triangle to give off the middle and *the left hepatics* (*Fig 22*) *In cholecystectomy*, such sinuosities of the right he

patic are extremely vulnerable for the cystic may arise from the distal or the proximal end of the loop in the latter instance crossing it (Plate II Nos 22 28) The U shaped loop may be nearer the cystic duct than the cystic itself (Plate II Nos 25 28) and it has been observed to overlie the point of union of the cystic duct with the hepatic duct (Plate II No 29)

As compared with the splenic artery tortuosity of the hepatic artery is relatively rare yet in some instances the right hepatic makes a full circle twist inside and outside the cystic triangle comparable with the loops effected by the tortuous splenic artery in aged individuals (Plate II Nos 33 34) In Calot s triangle such full loops may project dorsal or ventral to the cystic duct and carry the cystic with it (Plate II No 33) Amazing was the case in which the loop swung around an apparently split hepatic duct the right hepatic passing from a ventral to a dorsal position in its course and giving off the cystic and a liver branch as it did (Fig 98)

Site of Origin of the Cystic In the cystic triangle of Calot (the angle formed by the hepatic duct and the cystic duct) the site of origin of the cystic may be anywhere—high low or intermediate Frequently the two branches of the cystic come off separately the superficial arising low the deep high in the triangle (Plate V No 86) The two cystics may criss cross (Plate V Nos 97 99) The cystic may arise from the right hepatic before the latter has given off its first liver branch (Plate I Nos 5 8) it may arise from the first or the second branch of the right hepatic (Plate I Nos 9–12) after the first branch (Plate I Nos 13–16) or from a terminal liver branch (Plate I No 17)

In addition to giving off relatively large twigs to the liver before reaching the gallbladder (Plate I No 20) the cystic itself may be a liver artery i e after supplying the gallbladder with a number of branches it proceeds onward under the gallbladder to enter the liver (Plate IV No 67) Both the superficial and the deep branches of the cystic after supplying the gallbladder may enter the liver as large liver arteries

In many subjects (20 per cent) the cystic does not arise in Calot s triangle at all but is given off by the right hepatic before the latter has crossed the hepatic duct or while doing so (Plate IV Nos 69–75) This mode of origin of the cystic is a prevalent pattern when the cystic arteries are dual the deep arising in the triangle the superficial outside it and to the left of the hepatic duct or vice versa (Plate V Nos 90 91) With few exceptions such cystics from the left side including those from the middle and the left hepatics cross the hepatic duct anteriorly to reach the triangle of Calot When the entire cystic or its superficial branch arises from the gastroduodenal or its retroduodenal branch the cystic crosses the common bile duct either anteriorly or posteriorly the cystic artery coursing caudad to the cystic duct (Plate VI Nos 101 107)

As explained in the text and depicted in the illustrations the relations of the cystic artery and of the right hepatic to the biliary ducts are extremely varied and far too complicated to be remembered individually by the surgeon However this does not preclude the possibility of a quick recognition of the cystic technically speaking From this study of anatomic relations learned by dissection and from the successful procedure of experienced surgeons there ensues but one logical conclusion—viz that the cystic artery should be looked for on the gallbladder itself (i e as the cystic artery comes in contact with it) However it should be borne in mind that often there are two cystics as well as two right

hepatics and that the right hepatic in virtue of its varied origin, its irregular course and its sinuosities, may be close to the cystic duct occasionally crossing it anteriorly, more often posteriorly

In most instances the cystic can be picked up at the medial side of the gall bladder, where it usually divides into a superficial and a deep branch which ultimately anastomose at various points Since the superficial branch ramifies on the free peritoneal surface of the gall bladder where it can be seen readily, by following it medially and caudally the deep cystic in the majority of cases comes to view If not then most likely two cystics are present the site of origin of the deep cystic often being high and hidden Not infrequently the superficial cystic leaves the cystic triangle and swinging around the cystic duct dorsally approaches the peritoneal surface of the gallbladder from below and laterally (Fig 31) a common procedure when the cystics are dual (Plate II No 37 Plate V No 94 Fig 77)

Surgically considered, the deep (posterior) cystic is the one most apt to be injured or missed, especially when it arises separately and high in the triangle or is derived from an artery outside the triangle In addition to supplying the hepatic aspect of the gallbladder like the superficial cystic it gives numerous twigs to the liver some of them extending far beyond the confines of the gall bladder When inadvertently cut or torn the deep cystic may bleed profusely The resultant hemorrhage may be very annoying as the stem of the deep cystic is apt to retract deep into the liver substance making its retrieval and the stoppage of bleeding an arduous and disconcerting task A repeated perusal of the origin and the anatomic relations of the deep cystic as described in the text and shown in the illustrations should help considerably in forming a definite concept of its relations and its functional significance

The Retroduodenal Artery and Its Relation to the Common Bile Duct

The retroduodenal artery, as such is not described in most texts of anatomy or *surgery and thus far has not had a* generally accepted name Although 200 years ago (1756) Haller first called attention to the artery (a duodenalis post s dext s sup) it remained an unmentioned and a dubious vessel until Wiart (1899) again described the artery under the term artère pancreatico duodenale superieure After Wiart s work, a few investigators made mention of the artery but standard texts on anatomy continued to omit it Belou of the University of Buenos Aires (1915) revived the classical description of the course taken by the artery behind the head of the pancreas as given by Haller Verneuil Wiart, Sousloff Descomps and Rio Branco and named the artery pancreaticoduodenal posterosuperior Petren of Sweden in 1929 named the artery the superior pancreaticoduodenal posterior (a term adopted by Pierson Woodburne) to distinguish it from the superior pancreaticoduodenal *anterior* coursing on the anterior aspect of the head of the pancreas Edwards of Ohio University (1941) was the first to use the (Wilkiean) term ' retroduodenal to designate the artery

To focus attention on the artery coursing behind the duodenum and the head of the pancreas the present author will use the term retroduodenal for such the artery is in its chief distribution (as illustrated in all the author s figures) It is in virtue of this artery that the duodenum is the only section of the gut which has a double arterial arcade one anterior the other posterior a fact clearly described and illustrated 50 years ago by Poirier and Charpy who stated that every duodenopancreatic

artery (superior pancreaticoduodenal) divides into two branches one passing anterior and the other posterior to the head of the pancreas both forming an arcade with branches to the duodenum

The retroduodenal is a relatively large artery (1 to 3 mm) and with few exceptions is the first branch of the gastroduodenal as shown in most of the author s illustrations Its site of origin lies above the duodenum and the head of the pancreas and is often cryptic being hidden by dense fibrous tissue and pancreatic tissue In its tortuous course it descends for a short distance along the left side of the common bile duct crosses its supraduodenal portion anteriorly and again descends for a centimeter or more along the right side of the common bile duct (Figs 60 61) At about the middle of the posterior surface of the head of the pancreas behind the intrapancreatic part of the common duct it forms the U shaped posterior pancreaticoduodenal arcade branches of which usually supply all three parts of the duodenum and to a lesser extent the head of the pancreas in the back (Fig 66) In its secondary or tertiary arcades and in the number of duodenal branches (7 to 10) arising from it the retroduodenal arcade is more extensive than the anterior duodenal arcade made by the superior pancreaticoduodenal It is accompanied by a venous arcade which lies superficial to it and drains into the portal vein (Fig 37) Ramifications from the retroduodenal artery about the supraduodenal the retroduodenal and the intrapancreatic portion of the common bile duct (which it crosses twice first anteriorly then posteriorly) accounts in a large measure for the rich vascularization of the common duct the latter again being crossed near its distal end by branches from the retroduodenal arcade (Fig 52)

Topographically considered the course of the posterior pancreaticoduodenal arcade made by the retroduodenal artery is more cephalad than that of the anterior (Fig 60) Its beginning is deeply situated and accordingly is more difficult to find than that of the anterior Its pancreatic branches are superficially placed few in number and of smaller caliber than those of the anterior arcade which go deeply are more abundant and show extensive anastomose (Fig 68) Both arcades may communicate at various points with one another or with other regional arteries especially the dorsal pancreatic (Figs 59 60) Ultimately they unite with the superior mesenteric via a common inferior pancreaticoduodenal (Fig 49) or each arcade has its own inferior pancreaticoduodenal (Fig 50) *The latter, in some instances arises from an aberrant right hepatic derived from the superior mesenteric* (Fig 88) *from a jejunal branch* (Fig 72) *or from a dorsal pancreatic springing from the superior mesenteric* (Fig 76) One or the other or both arcades may be double even triple entirely or only in part (Figs 48 60 68)

The retroduodenal artery is of decided surgical importance first and foremost in cholecystectomy, for the entire cystic artery or its superficial branch may take origin from it (Figs 40 47) In ligations explorations or transplantations of the common bile duct especially of its intrapancreatic portion the retroduodenal should be taken note of to avoid annoying hemorrhage so widely experienced and recently referred to by Lahey In hidden bleeding which follows spontaneous rupture of the posterior duodenal wall by ulceration the retroduodenal may be involved more so than the supraduodenal or the gastroduodenal The retroduodenal may be ligated immediately after its origin from the first part of the gastroduodenal (Fig 10) this being far above the origin of the superior pancreaticoduodenal or at its distal end which unites with the *superior*

mesenteric via a separate and higher inferior pancreaticoduodenal (Fig 16) *or joins a posterior branch of the common inferior pancreaticoduodenal* (Fig 17) the latter then also receiving the anterior pancreaticoduodenal arcade The retroduodenal arcade comes to perfect display after mobilization of the duodenum and removal of the thin film of connective tissue that overlies it and the retroduodenal venous arcade (*Treitz s fascia* remnant of the primitive mesoduodenum)

Belou s Description of the Retroduodenal Artery

Belou of Buenos Aires (1915) termed the artery coursing in arcade fashion on the posterior surface of the head of the pancreas the pancreatico duodenal postero superior He found it to be a collateral branch of the gastroduodenal before the latter divided into its terminal branches in 97 per cent and as a collateral branch of the pancreaticoduodenal anterior and superior in 3 per cent Almost constantly it arises from the supraduodenal segment of the gastroduodenal It courses obliquely or transversely to the right crosses in front of the choledochus (at times behind) then descends behind the head of the pancreas being in the first part of its course to the right of the retropancreatic choledochus Coursing to the left in a scalloped arcade it again crosses the common bile duct and ultimately anastomoses with a posterior (bifurcated) ramus of the inferior pancreaticoduodenal from the superior mesenteric

Sites of origin of the retroduodenal artery were listed as follows

1 From a gastroduodenal normally placed to the left of the retroduodenal choledochus After crossing in front of the latter it reaches its right border where it becomes retropancreatic (26 per cent)

2 From a gastroduodenal which to the left is related to the retroduodenal choledochus It crosses this obliquely or transversely above the superior border of the head of the pancreas in front of a segment of the anterior surface of the portal vein Gaining the posterior surface of the head of the pancreas it passes to the left of the choledochus *without crossing* the latter (22 per cent)

3 From a gastroduodenal which to the left has relations with the retroduodenal part of the choledochus Crossing in front of the portal vein from left to right it crosses *behind* the choledochus transversely and descends on its right side to become retropancreatic (6 per cent)

4 From a gastroduodenal that has *already* crossed the retroduodenal choledochus in front In one type of this kind the artery maintains a short suprapancreatic course then runs parallel and above the right border of the retroduodenal choledochus (24 per cent) in another type the artery stays to the right of the choledochus at the superior border of the pancreas (22 per cent)

In 26 per cent the pancreaticoduodenal posterior superior is precholedochal taking a laterocholedochal course to the right It crosses the choledochus at the level of the superior border of the pancreas or over its retroduodenal segment In 46 per cent, the artery is solely laterocholedochal to the right In 22 per cent it is laterocholedochal to the left In 6 per cent it is retrocholedochal and laterocholedochal to the right

In its retropancreatic part the artery anastomoses with the posterior ramus of the inferior pancreaticoduodenal constituting an arcade on the posterior surface of the head of the pancreas *where it has intimate relations with the retropancreatic part of the choledochus* Two types of arcades are most prevalent In one the arcade is precholedochal or retrocholedochal above but retrocholedochal below The arcade descends along the

internal border of the second part of the duodenum and *after crossing* the retropancreatic choledochus posteriorly turns to the left to anastomose with a posterior branch of the superior mesenteric (78 per cent) In the second type the arcade starts from a pancreaticoduodenal posterosuperior that is lateracholedochal to the left Reaching the posterior surface of the head of the pancreas *it remains entirely to the left of the choledochus* ending likewise in the superior mesenteric via a posterior branch of the superior mesenteric (22 per cent) In the latter type the duodenal rami (1–9) emitted from the convex border of the arcade are larger and thicker for they must cross the choledochus to reach the duodenum In its supraduodenal course the pancreaticoduodenal posterior superior supplies the common bile duct with rami as it also does when coursing behind the pancreas

A venous arcade always accompanies the arterial arcade It may be contiguous to the latter separated from it by varying intervals or be intertwined with it In some instances it becomes disposed to the left of the choledochus

The Supraduodenal Artery of Wilkie to the First Part of the Duodenum

The retroduodenal artery is not to be confused with the supraduodenal artery of Wilkie This independent artery supplies the upper anterior and the posterior surfaces of the first part of the duodenum for an inch or more It is not so large (1 to 2 mm) as the retroduodenal and has a decidedly more varied origin Often springing from the retroduodenal before the latter has crossed the supraduodenal portion of the common duct (Fig 50) it may arise from the gastroduodenal (Fig 61) the hepatic (Fig 34) the right hepatic (Fig 11) the middle hepatic (Fig 10) and the right gastric (Fig 49) of which it commonly is a major branch *The supraduodenal is not an end artery, as claimed by Wilkie, for it frequently communicates with regional arteries,* especially the superior pancreaticoduodenal (Fig 70) the retroduodenal (Fig 78) the right gastric (Fig 59) the right hepatic (Fig 75) the dorsal pancreatic (Fig 93) and the splenic (Fig 91) It may arise from the superficial cystic (Fig 39) and in some instances consists of multiple branches springing from an arcade formed by the right gastric the gastroduodenal and the hepatic (Figs 51 59)

Reference to the supraduodenal artery from a surgical and a pathologic point of view was first made by Wilkie (1911) who gave the artery its name The artery supplies an area of the first part of the duodenum which has been regarded as *a critical one, in the sense that a vascular insufficiency in this region is supposedly associated with chronic ulceration and liability to leakage after pylorectomy* The critical area on the first part of the duodenum was known to William J Mayo who called attention to the fact that when the pylorus and the first part of the duodenum are pulled down at operation an anemic spot appears on the anterior wall of the duodenum According to Wilkie stretching of the supraduodenal artery distributed to this area is the factor producing the pallor Be that as it may the artery should hence forth be included in all texts of anatomy and surgery for it is often involved in massive bleeding of the duodenum a sequence to spontaneous rupture of peptic ulcers on the posterior wall of the first part of the duodenum

Summary of the Blood Supply of the Liver and the Gallbladder

The conventional textbook description of the arterial blood supply of the liver occurs in *only about one half of the population (55 per cent) while that of the gallbladder (cystic from the celiacal right hepatic in the cystic triangle*

of Calot) occurs in only 65 per cent. The cause of this amazing deviation from the so-called normal is the varied anatomy of the celiac artery. When typical and complete, the celiac has three branches—the left gastric, the splenic (lienal) and the hepatic, constituting a complete hepatolienogastric trunk. The latter may be incomplete when the right *or the left hepatic arises from some other* source, constituting an incomplete hepatolienogastric trunk *(25 per cent). Hence, in a complete or an incomplete* form, a hepatolienogastric trunk occurs in 90 per cent of the cases, all the remaining types comprising 10 per cent.

Typically, the hepatic artery supplies three branches to the liver: the right, the left and the *middle hepatics*. The last furnishes the blood supply to the *quadrate lobe (medial segment of the* left lobe of the liver, Healey and Schroy) and in the majority of instances, according to the author's extrahepatic dissections, is a branch of either the right hepatic (15 per cent) or the left hepatic (45 per cent). When the right or the left hepatic does not arise from the celiac artery, the latter becomes incomplete, and the missing right or left hepatic is replaced from another source (the right hepatic prevailingly from the superior mesenteric, the left hepatic from the left gastric). Such replacing hepatics are not to be confused with accessory hepatic arteries which are additive to the *normally present right and left hepatics derived* from the celiac but nevertheless are functionally essential, each having a selective distribution to a definite area of the liver, as demonstrable in the plastic casts of Healey and Schroy.

When a hepatic artery arises other*wise than from the celiacal hepatic*, it is known as an aberrant hepatic artery. Of these, there are two kinds: (1) replaced or accessory right hepatics; (2) replaced or accessory left hepatics. In some instances the entire hepatic artery is replaced—i.e., instead of arising from the celiac it takes origin from the aorta (3 cases), the *superior mesenteric* (5 cases) or the left gastric (1 case).

An aberrant hepatic (accessory or replaced) occurs in approximately every other body (12 per cent). While 35.5 per cent have but one aberrant hepatic, 10 per cent have two or more. In 200 subjects there were *52 cases (26 per cent)* of aberrant right hepatics and 54 *cases (27 per cent)* of aberrant left hepatics. *Surgically estimated, nearly one half of the aberrant left hepatics arising from the left gastric (25 per cent in 200) constitute the only left hepatics present, and three fourths of the aberrant right hepatics arising from the superior mesenteric (17 per cent in 200) are the only right hepatics present.* Otherwise stated, *in 11.5 per cent the left hepatic arose from the left gastric, in 12.5 per cent the right hepatic was derived from the superior mesenteric,* and the remaining *respective percentages were accessory hepatics.* In resections of the head of the pancreas a replaced right hepatic or the *common hepatic* arising from the superior mesenteric are in surgical danger, especially when the hepatic passes through the head of the pancreas. In gastric resections a replaced left hepatic or the entire hepatic (1 case in 500) arising from the left gastric are subject to such injury.

The basic types of the hepatic arterial blood supply may be categorized into 10 *types*. The normal type, with an incidence of *only 55 per cent*, has three celiacal hepatics (right, left and middle hepatics). The right or the left hepatic, in some instances, the middle hepatic may be replaced from a source other than the celiac artery, thereby constituting three different types. In addition to the normal three hepatics from the celiac, there may be an accessory right, an accessory left and in some instances both an accessory right and an accessory left hepatic, *thereby accounting for three*

more types A combination pattern of an accessory right hepatic with a replaced left hepatic or the reverse of this constitutes another type The remaining two types comprise a replacement of the entire hepatic from the superior mesenteric or from the left gastric (Figs 8 9)

The term celiac trunk denotes a complete celiac artery i e one having the left gastric the lienal and the hepatic and is synonymous with the term hepatolienogastric trunk The latter becomes incomplete when the right the left or the middle hepatic is derived from another source The celiac artery may have supernumerary branches such as the dorsal pancreatic artery the middle colic an accessory left gastric a hepatic an inferior phrenic or an accessory splenic branch (cardio esophageal superior polar)

When the left gastric is shifted from the celiac artery to the aorta to the hepatic or to the lienal the celiac trunk is incomplete and a hepatolienal trunk is formed (3 5 per cent) If the latter trunk takes on the superior mesenteric the trunk is a hepatolienomesenteric one The hepatic may become partially (right or left hepatic) or entirely dissociated from the celiac and become incorporated with the superior mesenteric constituting a split celiac viz a hepatomesenteric trunk and a gastrolienal trunk (5 5 per cent) Similarly the lienal may leave the celiac and join the superior mesenteric thereby splitting the celiac into a lienomesenteric trunk and a hepatogastric trunk (1 5 per cent) Very rarely all four branches (left gastric lienal hepatic and superior mesenteric) arise from a large common stem from the aorta constituting a celiacomesenteric trunk (2 cases in 500) *The fourth artery of the celiac may be the middle colic or an accessory middle colic in which case a celiacocolic trunk is formed (1 5 per cent)* Often (22 per cent) the fourth artery is the dorsal pancreatic The inferior phrenics take origin from it in 74 per cent The tripod of Haller occurs in 25 per cent a tetrapod formed by the addition of the dorsal pancreatic in 5 per cent

The cystic artery is often double (25 per cent) due to the fact that its superficial and deep branches have a separate origin in either the cystic triangle of Calot (angle formed by cystic duct and hepatic duct) or outside it

The site of origin of a cystic artery from the celiacal right hepatic or the aberrant right hepatic occurred in the cystic triangle in 81 per cent statistically considered *It is important to know that in so high a percentage as 19 per cent (38 cases) Calot s triangle was not the site of origin of the cystic artery* One triple cystic was observed

The typical celiacal right hepatic gave rise to the cystic in Calot s triangle in only 63 per cent Variations of such origin comprised single cystics 43 per cent double 11 5 per cent either the superficial or the deep branch of the cystic 8 5 per cent Aberrant right hepatics gave rise to cystic in the triangle in 18 per cent (36 cases) Replaced right hepatics from the superior mesenteric nearly invariably give off the cystic in Calot s triangle (24 cases 12 per cent) while an accessory right hepatic from the superior mesenteric may or may not give rise to a cystic (3 cases 1 5 per cent) The incidence of one or two cystics arising from an aberrant right hepatic derived from the superior mesenteric totals 13 5 per cent

The single cystic often arises from the right hepatic to the left of the hepatic duct i e before the right hepatic has crossed the hepatic duct posteriorly or anteriorly (26 cases 13 per cent) When the cystics are double either the superficial or the deep branch or both branches may have such origin from the right hepatic (13 cases 6 5 per cent) making a total of 19 5 per cent

The cystic may be derived from the left hepatic the middle hepatic or the common hepatic either as a single artery or only as a part of the cystic—i e its superficial or deep branch may arise to the left of the hepatic duct from such sources (Total 11 cases in 200 5 5 per cent)

The cystic may arise from the gastro duodenal or its retroduodenal branch either as the entire cystic or as its super ficial branch When of such origin the cystic crosses the common bile duct and is located caudad to the cystic duct (8 cases 4 per cent) The incidence of a cystic artery crossing the hepatic duct is very high (25 per cent 50 in 200) Such crossings are effected by single cystics 17 per cent by one of the double 7 5 per cent (superficial or deep branch) or by both branches

Because of its irregular course to and in the cystic triangle and the varied sites of origin of the cystic the right hepatic itself or one of its major branches may be injured or mistaken for the cystic This is readily feasible when a cater pillarlike looped section of the right hepatic abuts against the cystic duct or the common bile cystic *A liver branch of the right hepatic to a fissured area below the gallbladder (fissure made by a lateral extension of the porta hepatis) may readily be mistaken for the cystic especially when the right hepatic is de rived from the superior mesenteric* The branch of the right hepatic to the fis sured area is the posterior segmental branch for the posterior segment of the right lobe as seen in the casts of Healey and Schroy

The cystic gives off numerous twigs to the liver substance The superficial cystic after supplying the peritoneal or the free surface of the gallbladder com monly gives off twigs to the lateral side of the gallbladder the deep cystic con sidered surgically to be the more danger ous artery gives liver twigs to the medial side of the gallbladder to its bed and to the lateral and the distal ends of the gallbladder In some instances the deep cystic is of such large caliber that after supplying the gallbladder with many branches it continues on as *a liver artery* entering the latter distal or lateral to the gallbladder

The number of hepatic terminal branches entering the liver from all sources exclusive of those from the cystic is remarkably high and so varied that no two patterns are the same As statistically computed in 50 specimens 70 per cent had between 20 and 30 he patic terminal arteries and 10 per cent had between 30 and 40 The terminals were distributed selectively to definite areas of the liver a major portion of the small twigs entering the caudate and the quadrate lobes From this it would seem that the arterial vascularization of the liver like that of the spleen is effected in regional units and de facto this has been shown to be the true condi tion in the 150 plastic corrosion casts made at the Daniel Baugh Institute of Anatomy by Healey and Schroy

Extrahepatically there is an occasional anastomosis between the major liver ar teries between these and the aberrant right hepatics between the hepatic ar teries and the left gastric gastroduode nal retroduodenal and supraduodenal and between the cystic and the right or left hepatic In the fossa for the umbilical vein and in the area about the caudate lobe however there are extensive and frequent anastomoses between the ultimate and the pen ultimate terminals of the right the middle and the left hepatics Since most of the communicating vessels in the two regions specified are of twig size and subscapular in position it is highly im probable that they are capable of re establishing the circulation once a main artery like the right hepatic has been severed

In all bodies there is an extensive arterial arcade on the posterior surface of the pancreas which, in addition to its pancreatic branches, supplies all three portions of the duodenum in the back. It is made by the retroduodenal artery that arises from the gastroduodenal at a much higher level than the superior pancreaticoduodenal and independently of it. In its descent the retroduodenal forms a loop around the common bile duct crossing it anteriorly then posteriorly. It may be injured readily in explorations of the common duct and may be involved in hidden bleeding.

The supraduodenal artery of Wilkie supplies the upper anterior and the posterior surfaces of the first part of the duodenum for an inch or more. It is an independent artery of varied origin (gastroduodenal, retroduodenal, hepatic) and frequently communicates with the regional arteries. It may be involved in bleeding peptic ulcers.

Accessory hepatic ducts occurred in 18 per cent. They may join the hepatic duct (10 per cent), the right branch of the hepatic duct (3.5 per cent), the cystic duct (2 per cent) or the common bile duct (1 per cent). Their arterial relations are hazardous. *Those frequently found under the gallbladder (subvesicular ducts) may be filamentous and can be torn readily during cholecystectomy.* A disregard of accessory hepatic ducts courts injury to them with resultant disconcerting postoperative leakage of bile.

Dii laboribus omnia vendunt

—A stone inscription on an old building of the Jefferson Medical College founded 1825

7

The Human Liver

New Concept of the Segmental Division of the Liver

The old concept that the liver is divided into a right and a left lobe by the falciform ligament, the left sagittal fossa and the ligamentum venosum is erroneous and should be abandoned in texts of anatomy and surgery. The correct morphologic division line between the right and the left lobes is made by the lobar fissure, which, on the visceral surface of the liver, corresponds to a line extending *from the gallbladder inferiorly* to the fossa for the inferior vena cava superiorly (Fig. 3). A division of this type of bilaterality was first described by Cantlie, of Ireland, in 1898 and was substantiated by McIndoe and Counsellor in 1927 on the basis of a study of 42 human livers conducted at the Mayo Foundation, Rochester, Minn.

Hjortsjo, of Sweden, in 1948 called the main lobar fissure the "Hauptgrenzspalte," and in a publication in 1951 described its obliquity in detail along with the other fissures as he observed them in 10 plastic corrosion casts made of human livers. By means of his casts Hjortsjo was the first to show the segmental division of the liver, the segments outlined by him being a dorsocaudal, an intermediate and a ventrocranial segment for the right lobe and a dorsolateral and a ventrolateral segment for the left lobe. The disposition of arteries and bile ducts in relation to the main lobar fissure was also described by Elias and Petty of the Chicago Medical School (1952) as observed in five corrosion casts of human livers made with a plastic material, and in regard to bile ducts by Schmidt and Guttman of Dortmund, Germany (1951), in 11 human livers investigated roentgenologically after an injection of a barium sulfate suspension.

Without any knowledge of Hjortsjo's work, Healey and Schroy, of the Daniel Baugh Institute of Anatomy, at the suggestion *of the author*, began investigating the intrahepatic arrangement of bile ducts and blood vessels as visible in plastic casts made of them by injection of a solution of vinyl acetate. To date 150 corrosion casts of human livers have been made at the Daniel Baugh Institute of Anatomy. The specimens were obtained at autopsy from the departments of pathology of the Jefferson Medical College and the Pennsylvania Hospital. The ductal, the arterial and the portal systems were perfused with water under pressure and then dried by the injection of acetone and air. A 15 per cent solution of vinyl acetate containing 10 per cent (by weight) of barium sulfate was injected into the ducts under fluoroscopic vision to assure complete filling. The arteries were injected with a 12 per cent solution of vinyl acetate in acetone. The mercuric sulfide which was added to this solution gave it a red color and made it radiopaque. For the portal vein a blue color was used. In each case a roentgeno

gram was taken by Dr Healey following the injection After allowing the plastic to harden the liver was placed in a concentrated solution of hydrochloric acid for 24 to 36 hours in order to corrode the hepatic parenchyma After removal from the acid the specimen was washed with water to remove the remaining hepatic parenchyma and the cast was then ready for study

The plastic casts show that a main lobar fissure divides the liver into a right and a left lobe (Fig 3) No indication of the presence of this fissure can be seen on the parietal surface and it is readily observable only in casts in which the hepatic veins have not been injected for one of the main trunks of the hepatic veins (the middle) runs in this fissure within the liver substance In contrast with the hepatic vein no branches of the bile ducts the hepatic arteries or the portal vein ever cross the main lobar fissure in these casts

As readily observable in casts each lobe (right and left) is further subdivided into two segments by a fissure A right segmental fissure best seen when viewing the casts from the right side divides the right lobe into an anterior and a posterior segment (Fig 4) This right segmental fissure is complete extending into the porta hepatis It runs an oblique course and extends from the junction of the superior and the posterior surfaces downward in an anterior direction and terminates just in front of the lower border of the liver A comparable fissure—the left segmental fissure—divides the left lobe into a medial and a lateral segment (Fig 3) In position it corresponds to the surface markings customarily used to divide the liver into a right and a left lobe—i e on the parietal surface to the attachment of the falciform ligament and on the visceral surface to a line running through the umbilical fossa below and through the fossa for the ligamentum venosum above Like the right segmental fissure it is complete and extends into the porta hepatis Small branches of the bile ducts and the blood vessels often (20 per cent) cross this left segmental fissure

The lateral segment of the left lobe corresponds to the left lobe of the liver as usually described in textbooks The medial segment corresponds in part to what textbooks usually designate as the quadrate lobe However it should be noted that the medial segment not only constitutes a part of the visceral surface of the liver where the quadrate lobe usually is depicted but also includes all the area of the liver between the main lobar fissure and the left segmental fissure—in other words it comprises a part of the parietal surface as well The segments of the liver are shown in Figure 5

On the basis of its blood supply and biliary drainage four segments of the liver may be defined *to wit an anterior and a posterior segment for the right lobe and a medial and a lateral segment for the left lobe* As shown in Figures 6 and 7 the anterior and the posterior segments of the right lobe are supplied respectively by the anterior and the posterior segmental branches of the right hepatic artery and drained respectively by the anterior and the posterior segmental ducts of the right hepatic duct The medial and the lateral segments of the left lobe respectively considered receive their blood supply from the medial segmental artery and the lateral segmental artery (branches of the left hepatic artery) and are drained respectively by the medial segmental and the lateral segmental ducts (branches of the left hepatic duct) Each of the four segments of the liver is subdivided into a superior and an inferior area with one specific superior and inferior area bile duct and artery except for the medial segment where the area bile ducts and arteries are dual for both its superior and its inferior areas

The caudate lobe so far as its biliary drainage and its blood supply are concerned belongs entirely neither to the right nor to the left lobe Situated on the posterior surface of the liver between the inferior vena cava and the fossa for the ligamentum venosum it may be divided into the caudate lobe proper (i e the walnutlike protrusion into the bursa omentalis) and the caudate process whereby the caudate lobe is attached to the right lobe it being located between the porta hepatis below and the fossa for the inferior vena cava above According to its biliary drainage and arterial blood supply the caudate lobe may be divided into three parts (a) the caudate process (b) the right part of the caudate lobe prop r (c) the left part of the caudate lobe proper Prevailingly (44 per cent) three bile ducts drain and two arteries (47 per cent) supply the caudate lobe there being one bile duct for each of its parts one artery for the caudate process and the right half of the caudate lobe proper and one artery for the latter s left portion The typical patterns of the arterial blood supply and the biliary drainage of the four segments of the liver along with the most common pertinent variations will be discussed later

It is interesting to note as pointed out by Melnikoff (1924) and by Healey and Schroy that there is a striking similarity between the structures in the liver and the lung Developmentally considered both organs arise as entodermal diverticula which give rise to central tubular structures (the bronchial and the biliary trees) that grow into mesodermal tissue Each organ has two sets of afferent blood vessels one being nutritive (bronchial artery and hepatic artery) the other being functional (pulmonary artery and portal vein) Both organs have a single set of efferent channels (pulmonary vein and hepatic veins)

While the external gross morphology and the histology of both the lung and the liver have been well known for many years the concept of a segmental disposition of intrapulmonary and intrahepatic structures only recently has been emphasized from an anatomic and a practical point of view Pathologic lesions of the lung are often confined to one or more segments and are therefore removed surgically in accord with the segment(s) There may be a similar selective involvement of the segments and the lobes of liver with certain diseases as suggested over 60 years ago by Glenard (1890) who was among the first to report that certain diseases (diabetes) affect the right lobe while others (gastritis from alcohol) affect primarily the left lobe while biliary diseases affect the central portion In their report on the biliary drainage of the human liver Healey and Schroy describe and illustrate a large carcinomatous mass as being located in the posterior superior area of the right lobe where it caused a marked displacement of the bile ducts

As discussed by Healey and Schroy and by Norman (1951) Friesson and Rudhe (1954) of Sweden a knowledge of the intrahepatic segmental distribution of the bile ducts is becoming increasingly important to the roentgenologist and the surgeon Cholangiography first popularized by Mirizzi of Argentina (1932) as a roentgenologic method for exploring biliary ducts at operation is being utilized with increasing frequency As now employed the technic requires a laparotomy and has accordingly been used primarily for the localization of stones in the biliary tract at operation or during the postoperative period To overcome the objectionable feature of a laparotomy attempts are now being made according to Fainsinger (1950) to obtain a diagnosis by such methods as retrograde cholangiography injections of the gallbladder under peritoneoscopic control and blind puncture of the gall bladder With further improvement

cholangiography may become very useful in the diagnosis of various liver diseases as congenital anomalies of the bile ducts fibrotic conditions of the liver that cause the bile ducts to become narrow and tortuous or tumor formations that cause a displacement of the bile ducts However as stated by these authors and as exemplified in the early experiences with bronchography *one must first possess a knowledge of the normal anatomic pattern in order to interpret abnormal roentgen findings*

To the surgeon a knowledge of the intrahepatic anatomy of the bile ducts and the blood vessels is of paramount importance — first and foremost in the performance of a complete right or left hepatic lobectomy and in partial hepatectomies for removal of a solitary benign or malignant neoplasm To date according to Brunschwig (1953) 570 resected cases of liver tumors have been reported indicating that severe hemorrhage in liver surgery is not an inevitable complication Brunschwig further emphasizes the point that the danger of postoperative infection in liver surgery is no greater than in usual laparotomy *for in contrast with dogs whose livers are heavily infected with pathogenic anaerobes the human liver is sterile (Romieu and Brunschwig 1951)* If therefore an infectious process evolves after operation it must be ascribed to exogenous sources

A knowledge of the intrahepatic arrangement of bile ducts has a definite value in the newly devised reconstructive procedure of repairing a too short severed common hepatic duct i e in intrahepatic cholangiojejunostomy with partial hepatectomy as first introduced by Longmire in 1948 and modified by Wilson and Gillespie (1948) Cole and his associates Ireneus and Reynolds (1951)

Since the 150 plastic casts of Healey and Schroy show no evidence of the existence of an intrahepatic communication between the right and the left hepatic ducts (idem McIndoe and Counsellor) or between the parenchymatous branches of the right and the left hepatic arteries (idem Martens 1920 Wendel 1920 Glauser 1953) the conclusion is warranted that *every major artery of the liver (normal, replaced or accessory) supplies a definite segment of hepatic parenchyma and that every bile duct including the so called accessory hepatic duct drains a definite segmental area of the liver* As a closing remark it may be recalled that Bradley in 1909 aptly stated that the division of the liver as made by human anatomists is convenient but should not be held as resting upon an embryologic or true morphologic basis According to his investigations the liver is composed of three lobes a central and two lateral the umbilical fissure not being a true fissure

Anatomy and Nomenclature of the Hepatic Arteries Within the Liver

Introduction Despite 400 years of anatomy as begun by Andreas Vesalius of Belgium no adequate knowledge of the intrahepatic distribution of the branches of the celiac common hepatic and of the branches of aberrantly derived hepatics was available in any standard or specialized text of anatomy or surgery Many indeed have been the attempts to solve one of the most important problems in anatomy and surgery for if there is no intrahepatic anastomosis between the major hepatic arteries each having a selective distribution then none can be severed without serious consequence — i e necrosis of the area supplied The reports in the literature as regards the damage done to the liver when a main hepatic artery or an anomalous branch thereof has been cut at operative procedures have been sparse for obvious reasons but those that have been reported are harsh and *lead to but one conclusion viz, that severance of a right or a*

left hepatic distal to any collateral contributory branch inevitably leads to necrosis of the area supplied by the respective hepatic branch with resultant morbidity and death (Behrend Gordon Taylor Vaughn Gray Ramstrom Clauser) The anatomy involved in the ligation of the hepatic artery for portal cirrhosis (Rienhoff) and in the complete removal of the celiac artery for carcinoma of the stomach (Appleby) along with the 21 possible routes of collateral pathways to the liver are discussed in Chapter 14

Most recently (1953) Sven Ramström of Sweden in a study of 44 human bodies and as a result of experimental ligations of hepatic arteries in dogs drew the conclusion that certain obscure deaths after apparently uncomplicated biliary operations could well be due to unintentional ligation of an anomalous branch of the hepatic artery He showed that ligation of the major branches of *the hepatic artery distal to the right gastric* resulted in the death of all dogs in 17 days the mean survival time being 7 to 8 days. As a result of four years of research he claims that all hepatic lesions (toxic infectious and post traumatic) influence renal function impairing it and causing renal failure even though the kidneys previously were normal *This interplay between liver injury and renal insufficiency is known as the hepatorenal syndrome and injury to a hepatic artery, because of resultant necrosis of hepatic parenchyma may lead to renal insufficiency* The uremic patient after a cholecystectomy has always been a disconcerting problem

In short more knowledge should be available not only as regards the extrahepatic disposition of the hepatic arteries but also as to their functional significance and distribution once they enter the liver That phase of anatomy has now been solved to a large extent by the 150 plastic casts made at the Daniel Baugh Institute of Anatomy by Healey and Schroy Before presenting their findings a review of antecedent attempts to ascertain the intrahepatic arrangement of hepatic arteries should be given As this would entail a long text references to some of the outstanding contributions on the topic will be deemed sufficient for orientation purposes

Noteworthy investigations on the intrahepatic arrangement of the hepatic arteries are those of Kiernan (1833) Rex (1888) Mall (1906) Evans (1912) Martens (1920) Wendel (1920) Segall (1923) Melnikoff (1924) McIndoe and Counsellor (1927) and with newer methods those of Hjortsjö (1948–51) Elias and Petty (1952) and Glauser (1953) The work of McIndoe and Counsellor contains as excellent review of the literature on the structure of the liver on the various theories proposed as to the composition of its lobes (1 to 6) and on the various concepts as to the mode *of the liver s vascularization and* biliary drainage including Serege s (1901) concept that there are two distinctly different blood flows one arising from the mesenteric area and going to the right side of the liver the other arising from the splenic and proceeding to the left side a theory now abandoned

A few investigative items might be emphasized

In his *Anatomia hepatis* published in 1654 Glisson gave the first description and illustration of the intrahepatic arrangement of the portal and the hepatic venous systems and of the hilar part of the arterial and the ductal systems More *than 200* years later (1888) Hugo Rex Prosector at the Anatomical Institute of Prag examined the intrahepatic arrangement and the distribution of blood vessels and ducts of numerous mammals including man by injecting livers with a cementing substance On the basis of corrosion specimens obtained by washing away the liver tissue he established a

regional nomenclature of the major branches of the portal vein, the hepatic vein, the hepatic duct and the hepatic artery. This long, profusely illustrated and classically written article was entirely overlooked, not a single reference to it having been made in any standard text on anatomy, albeit the Rex terminology was adopted in part by Mall (1906), Evans (1912) and Melnikoff (1924).

As early as 1906, Mall, of Johns Hopkins University, in speaking of the intrahepatic circulation, stated that "There always has been and still is much confusion regarding the distribution of the hepatic artery. . . ." In his extensive study of the structural development of the liver he calculated that there were over a million small terminal arteries in the liver, one for every portal unit. The arterial branches that spread out toward the capsule of the liver after supplying the subcapsular portal units directly communicate with the hepatic veins. When he injected whipped blood into the hepatic artery of fresh livers, three fourths of it came out of the portal vein and one fourth out of the hepatic vein. Injections showed that the portal vein never comes to the surface of the liver and never anastomoses. By making reconstructions of the vascular system, Mall was able to demonstrate that in human embryos of 24 mm. all of the important vessels of the adult are formed completely.

A completely forgotten work is that of Francis Kiernan, who, in a paper published in the Philosophical Transactions in 1833, gave the first accurate description of the structure of the human liver and the relationships of its blood vessels to constituent lobules. In 1654 Glisson was of the opinion that prolongations of the hepatic capsule afforded support to the weight of the liver. Kiernan was the first to show that Glisson's capsule consisted of three parts—vaginal, interlobular and lobular—in each of which vessels ramify. An excerpt from Kiernan's description of Glisson's capsule (cited from Cameron and Mayes, 1930) reads:

"Glisson's capsule is not mere cellular tissue; it is to the liver what the pia mater is to the brain. It is a cellulo-vascular membrane in which the vessels divide and subdivide to an extreme degree of minuteness, which lines the portal canals, forming sheaths for the larger vessels contained in them, and a web in which the smaller vessels ramify, which enters the interlobular fissure and with the vessels forms the capsules of the lobules, and which finally enters the lobules and with the blood vessels expands itself over the secreting biliary ducts.

"In those subjects in which the capsular arteries are numerous these vessels cover the surface of the liver with a beautiful plexus; those of the right lobe anastomose with those of the left, and both anastomose with branches of the phrenic, internal mammary and suprarenal arteries; some leaving the liver ramify under the peritoneum covering the right kidney; others pass along the ligamentum teres to the umbilicus and anastomose with the epigastric arteries. The lobules are sparingly supplied with arterial blood. These bodies cannot be coloured with injection from the artery even in young subjects; in the adult, after the normal successful injection, when the arteries of the cellular capsule, those of the excreting ducts and gall bladder and the vasa vasorum are minutely injected, a few injected vessels only are detected entering the lobules" (*J. Path. & Bact.* 33:799, 1930).

Martens of Germany (1920), in an extensive investigation of human livers injected with barium and bismuth and then examined in roentgenograms, concluded that despite the small amount of anastomosis at the periphery and in the capsule of the liver *the right and the left hepatic arteries are essentially end arteries in the sense of Cohnheim*. His chief, Dr. Wendel (1920), came to the same conclusion with similar roentgenographic studies. Wendel stated that in his first resection of the right lobe of the

liver performed in a woman the greatest danger was the maintenance of an adequate blood supply He had to wait 9 years—i e until the woman died—for a postmortem examination of the anatomic changes effected by the operation

Segall of McGill University Canada (1923) investigated 55 human livers obtained at autopsy Of these 37 were injected with an emulsion of barium sulfate gelatin and then studied in stereoscopic pictures When either the left or the right hepatic was tied off and then injected with barium sulfate the entire arterial tree became filled Since barium does not pass through capillaries Segall concluded that the anastomoses between the right and the left hepatic arteries are made up of larger vessels Since the inferior phrenics were invariably filled with the emulsion he concluded that they were obviously in communication with the intrahepatic arterial branches Via the subcapsular plexus anastomoses with the inferior phrenics were claimed to have been established (1) in the coronary and the triangular ligaments (2) in the areolar tissue between the diaphragm and the liver (3) in the bare areas of the liver

The work of Melnikoff (1924) is very extensive and well illustrated being an investigation of 113 human livers studied with frozen sections formalinized sections of the visceral surface of the liver and roentgenograms While his illustrations depict the complexity of the ramifications of the vascular bed of the hepatic arteries and in particular of the portal vein no nomenclature of the branches of the hepatic arteries was made

In an investigation of plastic corrosion casts of human livers Hjortsjo of Sweden (1951) was the *first* to demonstrate the segmental distribution of the branches of the hepatic artery the bile ducts and the portal vein However the arterial nomenclature he devised is too cumbersome and confusing being in Latinized form and relationally considered very difficult to interpret The same may be said of the nomenclature followed and modified by Elias and Petty (1952) in their study of the human liver The number of corrosion casts studied by the respective authors (Hjortsjo 10 Elias and Petty 5) is far too small to depict and to evaluate adequately existent constitutional variations The new nomenclature devised by Schmidt and Guttman of Germany (1954) while classical and Latinized awaits further comment and consideration

The work of Glauser (conducted under Batson in the Graduate School of Medicine of the University of Pennsylvania 1953) denies the existence of intrahepatic arterial anastomosis After studying some of the present author s dissected specimens and noting the large number of small hepatic branches entering the liver (20 and more) Glauser obtained fresh human livers at autopsy and injected single small hilar branches of the hepatic and then the major hepatic trunk with a roentgenopaque material The x ray appearance of the livers showed that the hepatic arteries are *end arteries,* there being no anastomosis between them Every small hilar branch of the hepatic that had been injected was clearly outlined in its ramifications and supplied but one pyramidal lobule On this basis Glauser likewise raised the question whether some cases of postoperative hepatorenal syndrome could not be due to an accidental occlusion of a relatively large end artery

Observations on Plastically Casted Intraorganic Hepatic Arteries In this study of the intrahepatic distribution of the single hepatic artery and the multiple hepatic arteries by Healey Schroy and Sorensen Healey did most of the analysis of arterial relations and was the author of the text the present author s part in the contribution being but a critical one and instanced only when needed

The plastic casts of human livers used for this investigation were the same as those made by Healey and Schroy and used for the analysis of the intrahepatic biliary tree for from the beginning of this long and arduous investigation (150 plastic corrosion casts) ducts and blood channels were injected with diversely colored plastic material to bring out their true relation to one another For this intrahepatic arteriographic study Healey et al chose 70 casts in which the hepatic artery had been injected with a solution of vinyl acetate in acetone colored with mercuric sulfide In 10 of these casts the hepatic artery was single in 30 cases more than one hepatic artery supplied the liver

Healey et al were not concerned with the sites of origin of the hepatic artery or of the cystic artery as this phase of the problem had been under investigation by the author for over 10 years in his studies of the celiac axis and its variants However it is interesting to note that independent of any of the author s samples Healey et al observed the incidence of a single common hepatic to be 57 per cent which is in agreement with the present author s statistical record of 58 5 per cent in 200 bodies

The extrahepatic observations made by Healey et al were (1) bifurcation of the common hepatic may take place anywhere between the origin of the vessel and the porta hepatis (2) the division point of the hepatic was not in line with the lobar fissure as was the case with the bifurcation of the common hepatic duct but was situated to the left of this fissure thereby effecting a longer length of the right hepatic (3) in 87 per cent the right hepatic passed behind the hepatic duct (4) division of the right hepatic may take place (a) in the hepatic parenchyma (b) extrahepatically in the porta to the left or the right of the hepatic duct (5) two right hepatics may be present (1 case) due to the fact that the anterior and the posterior segmental branches of the right hepatic were not given off inside the liver but outside it —a phenomenon which the present author has observed rather frequently as depicted in his illustrations

Blood Supply of the Right Lobe Like the right hepatic duct the right hepatic artery once inside the liver divides into an anterior and a posterior segmental branch (anterior segment artery posterior segment artery) to supply the respective segments of the right lobe viz the anterior and the posterior segments Both of these segments have superior and inferior areas and accordingly are supplied by superior and inferior area branches of the segmental arteries In position the arteries usually run below the corresponding bile ducts (Fig 7)

Anterior Segment Artery In its site of origin from the right hepatic the anterior segment artery usually is inferior in position and often takes a tortuous course It is this artery that in many instances makes the well known caterpillar like loop into the confines of the cystic triangle of Calot thereby placing the artery in a vulnerable position during cholecystectomy Prevailingly the anterior superior area artery takes origin from the anterior segment artery in 87 per cent while the anterior inferior area artery arises from it in 86 per cent Variations the anterior superior area artery from the posterior segment artery in 10 per cent from the left hepatic (1 case) the anterior inferior area artery from the posterior segment artery in 14 per cent

Posterior Segment Artery It accompanies the posterior segment bile duct the artery running along the lower border of the latter Like its corresponding duct it divides into a superior and an inferior area artery for the respective superior and inferior areas of the posterior segment Prevailingly the superior area artery of the posterior segment arises

from the posterior segment artery in 86 per cent while the inferior area artery of the same segment arises from it in 77 per cent Variations the superior area artery of the posterior segment from the anterior segment artery in 12 per cent directly from the right hepatic in 2 per cent the posterior inferior area artery from the anterior segment artery in 20 per cent from the right hepatic in 3 per cent

In casts in which the cystic artery was injected it proved to be single in 19 cases and double in 6 cases Most frequently the cystic arose from the right hepatic (27 cases) less frequently (18 per cent) from the anterior segment artery which likewise is often the site of origin of the deep cystic branch The subvesicular accessory bile duct commonly present in a superficial position in the gallbladder bed (35 per cent), was accompanied by a subvesicular artery in 5 per cent

Blood Supply of the Left Lobe The left hepatic artery follows the prevailing pattern of branching of the left hepatic duct (67 per cent) in only 40 per cent —i e the artery terminates by dividing into a medial and a lateral segment artery for the respective medial and lateral segment of the left lobe (Fig 7) Instead of dividing into two segment arteries the left hepatic often (35 per cent) exhibits an early division into the superior and the inferior area arteries for the lateral segment the division occurring to the right of the left segmental fissure in the porta In such cases the medial segment artery (the middle hepatic in the author s illustrations) arises from either the lateral superior or the *lateral inferior area artery* *This pattern* of division was seen in the branching of the left hepatic duct in 31 per cent

In many instances (25 per cent) no true left hepatic artery exists the medial and the lateral segment arteries arising separately from the common hepatic artery A comparable nonunion of the medial and the lateral segmental bile ducts was observed in only 2 cases On the right side separate segment bile ducts enter the common hepatic duct rather frequently (27 per cent) so likewise separate segment arteries on the left side arise from the common hepatic artery with a comparable frequency (25 per cent)

MEDIAL SEGMENT ARTERY (THE ARTERIA HEPATICA MEDIA OF HALLER TIEDEMANN AND ADACHI) This terminal branch of the hepatic artery is not mentioned in modern textbooks of anatomy or surgery (except in the new 11th Edition of the Schaeffer Morris *Human Anatomy*) yet it is a very important one since the cystic artery frequently arises from it and as shown in the author s illustrations in some instances it is the only celiacal hepatic supplied to the liver Healey et al termed it the medial segment artery as it supplies the medial segment which is more extensive in volumetric proportion than the quadrate lobe to which the author s drawings always orientate the middle hepatic artery

According to the casts of Healey and Schroy the medial segment artery arose as a terminal branch of the left hepatic in 40 per cent which compares favorably with the author s findings of extrahepatic dissection viz from the left hepatic 45 per cent the other sources of observed origin in the 200 bodies dissected by the author being right hepatic 45 per cent and a 10 per cent origin from other sources (as the celiac the gastroduodenal the hepatic or the right gastric)

The casts of Healey and Schroy have enhanced the author s concept of the *middle hepatic* for in extrahepatic dissection its branches can be seen only as they enter the liver their ultimate distribution being undiscernible In the plastic casts the medial segment artery *unlike other segment arteries* gave off *four* area branches instead of two as

typically the case with the anterior and the posterior segment arteries of the right hepatic and as true of the lateral segment artery of the left hepatic. There are then *two* superior and *two* inferior area arteries for the medial segment encompassed partly in what textbooks describe as the quadrate lobe. Aberrant sites of origin of the medial segment artery, according to Healey et al., are from the common hepatic (25 per cent), from the superior or the inferior branch of the lateral segment artery, its origin from the lateral inferior artery being more frequent.

In the casts of Healey and Schroy four types of biliary drainage of the medial segment bile duct were discernible; so likewise four types of arterial branching of the medial segment artery were encountered. These comprise: *Type I*, in which two inferior and two superior area arteries form a single medial segment arterial trunk (70 per cent); *Type II*, in which three of the four area arteries arise from a single trunk and one from a separate site (20 per cent); *Type III*, in which two superior and two inferior arteries arise as separate trunks (5 per cent); *Type IV*, in which two area arteries arise separately and two arise from a common stem (5 per cent).

In the casts, the medial segment artery (middle hepatic) gave off branches to the caudate lobe and subcapsular branches to the tissue in the region of the umbilical fossa. The author's comment on these subcapsular branches from the middle hepatic, as discernible in extrahepatic dissections, is as follows: they are very numerous, extremely fine, exhibit extensive extrahepatic anastomoses, particularly with branches supplying the caudate lobe, and frequently traverse the umbilical fossa to join branches of the left hepatic.

LATERAL SEGMENT ARTERY. As one of the terminal branches of the left hepatic, the lateral segment artery runs along either the superior or the inferior border of the lateral segment bile duct and, in line with the left segmental fissure, usually (56 per cent) divides into its lateral superior area and lateral inferior area branches. Division to the right of the left segmental fissure occurs in 35 per cent, and in these cases the medial segment artery may arise from one of the branches of the lateral segment artery (as instanced in some of the author's illustrations).

The lateral superior area artery extends obliquely upward toward the upper outer angle of the lateral segment and throughout its course in the lateral segment is closely associated with the bile duct of the superior area of the lateral segment. At times it extends beyond the liver parenchyma into the appendix fibrosa situated between the leaflets of the left triangular ligament, where the vasa aberrentia, when present, are located.

The lateral inferior area artery, like the corresponding bile duct which it accompanies inferiorly, descends in the lateral segment, curves leftward, then upward to form a well-dimensioned scalloped arc. Many of the casts show subcapsular branches arising from the lateral segment artery or from its area arteries (which fact corresponds to extrahepatic dissection, as instanced in many of the author's drawings).

Blood Supply to the Caudate Lobe. From the point of view of its biliary drainage and blood supply, the caudate lobe belongs entirely neither to the right nor to the left lobe. As previously stated, the caudate lobe consists of three parts: (1) the caudate process, (2) the right and (3) the left portions of the caudate lobe proper. Prevailingly (44 per cent) the biliary drainage of the caudate lobe is via three bile ducts, one for each part. So likewise is the blood supply, but at a reduced incidence, for three separate arteries to the caudate lobe were encountered in only 30 per cent of

the casts Most frequently (15 per cent) only two arteries supplied the entire caudate lobe i e the branch to the caudate process and to the right part of the caudate lobe proper came from a common trunk while the branch to the left part was separate

In 23 per cent of the casts the entire caudate lobe was supplied by a single trunk only one case being encountered where the lobe had four arteries supplying it Sites of origin of the caudate arteries varied considerably in 35 per cent they arose entirely from the right hepatic and in 12 per cent entirely from the left hepatic

ABERRANT (ATYPICAL) HEPATIC ARTERIES As defined in the author s work *an aberrant hepatic artery is one arising from a source other than a typical celiac hepatic* Aberrant hepatic arteries comprise two types accessory and replaced the former being additive to the three normally present celiac hepatics the latter hepatics which take the place of a lacking celiac hepatic *From a statistical analysis of the author s dissections of 200 bodies it may be concluded that in the general population some sort of an aberrant hepatic artery (replaced or accessory) occurs in approximately every other body (41 5 per cent) and that 31 5 per cent have but one aberrant hepatic artery while 10 per cent have two or more*

In 70 of the plastic casts of Healey and Schroy investigated for this study 30 of them (43 per cent) had more than one main artery supplying the liver The source of these aberrant hepatics could not be determined as the investigation was based on excised autopsy specimens When two separate hepatic arteries entered the porta (27 of 30 cases) the intrahepatic distribution of them was as follows (1) one artery supplied the entire right lobe (anterior and posterior segments) the other was distributed to the entire left lobe (medial and lateral segments) (20 cases) From an extrahepatic dissection one or the other of these arteries could be regarded as a replaced right hepatic (2) one artery supplied the entire right lobe and the medial segment of the left lobe the other artery being distributed to the lateral segment (6 cases) (3) the larger of the two arteries supplied the right lobe and the major portion of the left lobe (medial segment and superior area of the lateral segment) while the smaller artery was distributed to the inferior area of the lateral segment and from extrahepatic dissection most probably represented a so called accessory left hepatic artery Three casts showed three separate hepatic arteries entering the liver The largest of these supplied the right lobe of the remaining two one supplied the medial segment the other the lateral segment

One cast proved to be exceptionally informative It was made from the liver taken from a 61 year old male body in which Healey had previously dissected five major hepatic arteries The common hepatic derived from a celiacomesenteric trunk gave off three hepatics One was dissected as the left hepatic but in the cast proved to be the artery supplying only the inferior area of the lateral segment The second artery was distributed only to the medial segment The third artery was dissected as the right hepatic but in the cast supplied only the posterior segment of the right lobe In addition there were two extrahepatic arteries arising from a source other than the celiac The one from the left gastric (accessory left hepatic) entered the superior area of the lateral segment the other from the superior mesenteric (an accessory right hepatic) supplied the anterior segment of the right lobe

Beyond any questioning this simple cast proves conclusively that *functionally considered there are no accessory he*

patic arteries and that each hepatic artery, whatever its source, has a selective distribution to a specific area of the liver parenchyma. Glauser's work (1953) on injections of single hepatic branches confirms this view, for his roentgenograms clearly demonstrate that each hepatic branch has a selective distribution in the liver, the single small branch being distributed to a single pyramidal lobule.

ARTERIAL ANASTOMOSES. Significant is the fact that in 70 casts Healey et al. observed absolutely no intrahepatic communications between the hepatic arteries (idem Glauser). The resultant conclusion is that grossly and intrahepatically considered the hepatic arteries are end arteries in the sense of Cohnheim. What the histologic aspect of the problem is remains to be determined.

The anastomoses between the hepatic arteries observed in the casts were restricted to the extrahepatic region and occurred with an incidence of 25 per cent. The communications comprised the following types: (1) between the caudate lobe arteries and the medial segment arteries or between two caudate arteries in the porta hepatis (plain and numerous in many of the author's illustrations); (2) between branches of the medial and the lateral segment arteries in the umbilical fossa (profusely pictured in the author's illustrations); (3) between the caudate arteries and the posterior segment artery of the right hepatic on the right side of the porta (very frequently illustrated in the author's drawings of the branch of the right hepatic that ascends on the portal vein and descends behind it to supply the caudate lobe). Healey et al. concluded with a discussion of currently practiced ligation of the hepatic artery for portal cirrhosis. The major anatomic features of this operative procedure and the routes of possible collateral pathways to the liver are presented by the author in Chapter 14.

Anatomy and Nomenclature of the Biliary Ducts Within the Liver

Previous to presenting a detailed description of the anatomy of the bile ducts within the human liver, as recently ascertained by Healey and Schroy of the Daniel Baugh Institute of Anatomy in a study of 100 plastic casts, a short survey of the antecedent literature on this important topic is essential for orientation purposes.

In a nearly forgotten classical work published in German in 1888, Hugo Rex, of the University of Vienna, was the first to study the intrahepatic course of the vascular and the bile channels by the injection-corrosion method, he having used a cement substance to obtain his casts. The livers he investigated comprised those of various mammals, mainly primates, relatively few being human. In his extended, well-written text and in his illustrations Rex gave a clear presentation of his findings, which pertained mostly to the vascular system. A photostatic film of his paper is available at the Congressional Library (Washington, D. C.), from which Healey obtained a copy.

In 1924, in a study of 113 human livers by injections, sections and roentgenograms, Melnikoff gave an extensive description of the intrahepatic vessels and the bile ducts, emphasizing in particular the portal system. Three years later McIndoe and Counsellor (1927), in a study of the intrahepatic ducts in 42 human livers, re-emphasized the concept of the bilaterality of the liver, as first suggested by Cantlie in 1898 and followed by Serege (1901), to wit, that the plane of division between the right and the left lobes lines up with the fossa for the gallbladder and the inferior vena cava on the liver.

Hjortsjo of Sweden (1948), in a study of 10 human livers by means of the corrosion method (casts) and cholangio

the casts. Most frequently (15 per cent) only two arteries supplied the entire caudate lobe, i.e., the branch to the caudate process and to the right part of the caudate lobe proper came from a common trunk, while the branch to the left part was separate.

In 23 per cent of the casts the entire caudate lobe was supplied by a single trunk, only one case being encountered where the lobe had four arteries supplying it. Sites of origin of the caudate arteries varied considerably: in 35 per cent they arose entirely from the right hepatic and in 12 per cent entirely from the left hepatic.

ABERRANT (ATYPICAL) *HEPATIC* ARTERIES. As defined in the author's work, *an aberrant hepatic artery is one arising from a source other than a typical celiac hepatic.* Aberrant hepatic arteries comprise two types, accessory and replaced, the former being additive to the three normally present celiac hepatics, the latter hepatics which take the place of a lacking celiac hepatic. *From a statistical analysis of the author's dissections of 200 bodies it may be concluded that, in the general population, some sort of an aberrant hepatic artery (replaced or accessory) occurs in approximately every other body (41.5 per cent) and that 31.5 per cent have but one aberrant hepatic artery while 10 per cent have two or more.*

In 70 of the plastic casts of Healey and Schroy investigated for this study, 30 of them (43 per cent) had more than one main artery supplying the liver. The source of these aberrant hepatics could not be determined, as the investigation was based on excised autopsy specimens. When two separate hepatic arteries entered the porta (27 of 30 cases) the intrahepatic distribution of them was as follows: (1) one artery supplied the entire right lobe (anterior and posterior segments), the other was distributed to the entire left lobe (medial and lateral segments) (20 cases). From an extrahepatic dissection one or the other of these arteries could be regarded as a replaced right hepatic. (2) one artery supplied the entire right lobe and the medial segment of the left lobe, the other artery being distributed to the lateral segment (6 cases). (3) the larger of the two arteries supplied the right lobe and the major portion of the left lobe (medial segment and superior area of the lateral segment), while the smaller artery was distributed to the inferior area of the lateral segment and, from extrahepatic dissection, most probably represented a so-called accessory left hepatic artery. Three casts showed three separate hepatic arteries entering the liver. The largest of these supplied the right lobe; of the remaining two, one supplied the medial segment, the other the lateral segment.

One cast proved to be exceptionally informative. It was made from the liver taken from a 61-year-old male body in which Healey had previously dissected five major hepatic arteries. The common hepatic, derived from a celiaco-mesenteric trunk, gave off three hepatics. One was dissected as the left hepatic but, in the cast, proved to be the artery supplying only the inferior area of the lateral segment. The second artery was distributed only to the medial segment. The third artery was dissected as the right hepatic but, in the cast, supplied only the posterior segment of the right lobe. In addition there were two extrahepatic arteries arising from a source other than the celiac. The one from the left gastric (accessory left hepatic) entered the superior area of the lateral segment, the other from the superior mesenteric (an accessory right hepatic) supplied the anterior segment of the right lobe.

Beyond any questioning this sample cast proves conclusively that *functionally considered, there are no accessory he-*

attachment of the falciform ligament on the parietal surface The medial segment corresponds in part to the quadrate lobe the lateral segment to the left lobe in the restricted textbook sense As on the right side each segment of the left lobe has a superior and an inferior area The lateral segment is divided into a smaller superior and a larger inferior area The duct of the inferior area is usually larger and longer than that of the superior area and characteristically courses through the lateral segment in an arc the concavity of which faces upward It usually receives the ducts draining the convex portion of the lateral segment thereby accounting for the larger size of the inferior area

The medial segment is drained by a medial segment duct (of the second order) formed however by *two* ducts coming from the superior area and by *two* ducts coming from the inferior area hence a total of four ducts these being of the third order The lateral segment duct (of the second order) is formed by the confluence of one superior and one inferior area duct these again being ducts of the third order

Data on ducts of the fourth order have been worked out by Schroy in his doctorate thesis Ducts of the fifth and the sixth orders are still visible in the plastic casts but beyond that the plastically cast ducts are too fine and brittle to assure accuracy of analysis and evaluation In short the problem resolves itself to histology and is still open for further investigation and information

Succinctly stated then as far as its biliary drainage is concerned the liver is composed of four segments There are two segments for the right lobe (anterior and posterior) disposed like the layers of a sandwich the meat being the oblique right segmental fissure The posterior segment corresponds largely to that portion of the liver related to the visceral surface the anterior segment comprises the remainder of the right lobe There are two segments for the left lobe disposed side by side the medial segment corresponding to the quadrate lobe projected to the parietal surface where no markings are visible the lateral segment comprises that part of the liver usually referred to as the left lobe in gross descriptions of the organ

As is true with every other structure in the human body manifold constitutional variations exist as regards the existent patterns of the intrahepatic biliary tree In the majority of the casts of Healey and Schroy (72 per cent) the anterior and the posterior segment ducts joined to form the right hepatic duct which averaged 9 mm in length with a range of 2 to 25 mm In 28 per cent no union took place between the segmental ducts In these cases the posterior segment duct drained into the left main hepatic duct in 21 per cent whereas the anterior segment duct drained into it in 7 per cent Lack of union of the right segment duct gives rise to what heretofore has been termed an accessory hepatic duct the nature of which will be discussed shortly

In the left lobe the medial and the lateral segment ducts usually (67 per cent) unite to form the left hepatic duct which is much longer averaging 1 7 cm in length The medial segment duct may drain into the inferior area duct of the lateral segment constituting an atypical union (25 per cent) When the medial and the lateral segment ducts fail to unite (2 cases) there ensues on the left side (as on the right) an accessory left hepatic duct the existence of which has been denied by some authors Two such left accessory hepatic ducts were encountered by the author in extrahepatic dissections and one by Schroy in his extrahepatic casts of the bile ducts

As obvious in the casts *the medial segment duct never crosses to the left of the left segmental fissure to enter the*

grams was the first to show that the branching of the bile ducts was segmental in nature The terms he devised for the specific segmental divisions of the liver and for the areas of bile drainage however are far too cumbersome and confusing in their Latinized form to be understood readily The same may be said of the work of Elias and Petty, of the Chicago Medical School (1952) who investigated the intrahepatic anatomy of 18 livers only a few of them being of the adult human type As previously stated the nomenclature of Schmidt and Guttman regarding the segmentally distributed intrahepatic bile ducts while much simpler than that of Hjortsjo awaits further appraisal and consideration To obtain a better interpretation of the cholangiograms in relation to disease Fainsinger of South Africa (1950) investigated the normal pattern of the hepatic duct in 35 human livers by means of the injection-corrosion method and roentgenograms The observations he made with the latter alone are not without question for in cholangiograms there is an overlapping of the anterior and the posterior segmental ducts making interpretation a difficult task

Plastically Casted Intrahepatic Bile Ducts[1]

Following the directional nomenclature of the intrahepatic bile ducts devised by Healey and Schroy in 1953 the biliary drainage of the human liver as ascertained in 100 plastic corrosion casts is as follows (Fig 6)

The right and the left lobes of the liver separated by the invisible lobar fissure (save in casts) are drained by their respective right and left hepatic ducts these being ducts of the first order The right lobe is further divisible into an anterior (ventral) segment and a posterior (dorsal) segment the division being made by an oblique complete fissure seen distinctly in casts on the right side and probably indicated in the intact liver by the fissured area often present under the gallbladder and depicted in many of the author s illustrations for the posterior segmental artery when dissectible outside the liver invariably enters this fissure (Fig 71)

The anterior and the posterior segments of the right lobe are drained by ducts of the second order viz the anterior and the posterior segment ducts the latter being longer and somewhat more superior in position Both the anterior and the posterior segments of the right lobe have a superior and an inferior area respectively drained by bile ducts of the third order—i e by branches of the segmental ducts

The left lobe of the liver is subdivided into a medial segment and a lateral segment by the left segmental fissure which is likewise visible only in casts but which is in line with the umbilical fossa and the fossa for the ligamentum venosum on the visceral surface and with the

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[1] In observations over a period of years on the variational patterns of the extrahepatic bile passageways especially the mode of formation of the hepatic duct and the incidence of accessory hepatic ducts (as revealed by the author s dissection of the biliary region in 200 bodies and as revealed in particular by Schroy in 50 specimens in which the extrahepatic ducts were injected with the plastic vinyl acetate under the author s direction for his M A thesis) it became quite evident to the author that these variations were intimately correlated and dependent upon the distribution and the arrangement of the bile ducts inside the liver Accordingly at the author s suggestion a major investigation on the variational anatomy of the biliary system inside 100 human livers was undertaken by Healey and Schroy the former an Assistant Professor of Anatomy the latter a Ph D graduate student of the Daniel Baugh Institute of Anatomy The cited investigators devised their own technic and made their own observations and statistical analysis The report of their findings was written by Healey without a possible prejudicial influence of the present author s opinion whose part in the investigative work was but a critical one—i e correlation and correction of the text when deemed necessary The mode of the segmental division of the liver and the method whereby this information was obtained by Healey and Schroy already has been discussed

as shown by Healey and Schroy (1953) They showed that the sites of drainage of the subvesical duct comprise anterior segment duct (16 cases) right hepatic duct (11 cases) posterior inferior area duct (1 cases) anterior inferior area duct (3 cases) left hepatic duct (1 case)

In no instance did the subvesical duct enter the gallbladder via the so called hepatocystic duct the existence of which is doubtful although Toufeeq of India and Pakistan in an article published by the National Medical Association (1953) resuscitated the anomaly largely publicized by the supposedly observed cases of Mentzer (1929—8 in 96 necropsies) and by the ingeniously wrought illustration of Grey Turner of England In 100 bodies statistically studied at the Daniel Baugh Institute of Anatomy of Jefferson Medical College as to the nature of the biliary ducts (200 of the authors extrahepatic dissections 50 of Schroy s extrahepatic vinyl acetate casts of bile ducts made for his M A degree [1951] and of 150 plastic casts made by Healey and Schroy of the entire biliary tree) no evidence was found for the assertions sometimes made that (a) a cystic duct opens directly into the duodenum (b) an accessory hepatic duct opens directly into the gallbladder (c) the right and the left hepatic ducts open into the gallbladder Belou (of Buenos Aires Argentina (1915) in his report of his dissections of 150 bodies (freshly preserved) never mentions the occurrence of cystohepatic ducts although he admits their presence in lower vertebrates

Vasa Aberrentia The vasa aberrentia of the appendix fibrosa first described by Ferrein in 1753 were encountered in the plastic casts of Healey and Schroy in 5 per cent and were found to be continuous with the lateral superior duct With the retrogressive decrease in size of the liver parenchyma after its maximal embryonic development these true biliary channels are left superficial in position maintaining their connection with the biliary tree Although apparently functionless (McIndoe and Counsellor) their presence should be kept in mind during an operative procedure as a total gastrectomy where the left triangular ligament with which the appendix fibrosa is related is incised in order to obtain a more adequate exposure

Accessory Hepatic Ducts In regard to accessory hepatic ducts Healey and Schroy noted that their incidence is far greater than generally reported they having encountered them in 28 per cent as opposed to the findings in extra hepatic dissections by Flint (1923) 15 per cent in 200 bodies Michels (1951) 18 per cent in 200 bodies Moosman and Coller (1951) 16 per cent in 250 bodies Healey and Schroy ascribe their higher percentage (28 per cent) of observance of accessory hepatic ducts to the superiority of their corrosion method over that of gross dissection which in view of the depth of the porta hepatis is rarely complete

The term accessory hepatic duct should be modified as meaning an aberrant segment or area duct for in reality they are not accessory hepatic ducts but rather cases in which no union of the anterior and the posterior segment ducts of the right lobe took place, or they represent cases in which there was an aberrant drainage of the area ducts into the extrahepatic bile tract

As a corollary it follows that the removal of the gallbladder should always be accomplished with care and circumspection lest by severance or tearing of a subvesicular duct (35 per cent) or of an accessory hepatic duct (28 per cent) the biliary tree be opened with resultant disconcerting postoperative leakage of bile and telling subsequent jaundice

In correlating their findings with the investigations of Hjortsjo of Sweden who was the *first* to outline the intra hepatic segmental arrangement of the

duct of the lateral segment. Four basic patterns of drainage of the medial segment occur. In Type I, the most prevalent (60 per cent), all four of the area ducts (two superior, two inferior) join to form a single medial segment duct. In Type II, next in frequency (21 per cent), one of the area ducts (usually the superior) has a separate drainage, the remaining three ducts forming a single trunk. In Type III the two inferior ducts and the two superior ducts, respectively considered, usually form a single trunk, each having a separate site of drainage (10 per cent). In Type IV, two ducts drain separately and two by a common stem (6 per cent). The site of drainage of the medial segment duct or ducts varies. In most instances (67 per cent) the medial segment duct joins the lateral segment duct to form the left hepatic duct. The medial segment duct, however, often (25 per cent) drains into the inferior duct of the lateral segment.

Caudate Lobe. As previously stated, the caudate lobe belongs exclusively to neither the right nor the left lobe as far as its biliary drainage and blood supply are concerned. *It consists of three* parts: (1) the caudate process, (2) the right portion and (3) the left portion of the caudate lobe proper. Prevailingly (44 per cent) three ducts drain the caudate lobe, one duct for each part. In 26 per cent the duct draining the caudate process and the duct draining the right part of the caudate lobe proper merged into a common duct, the duct draining the left part of the caudate lobe remaining separate. Sites of drainage of the ducts coming from the caudate lobe vary considerably. In 78 per cent drainage of the entire caudate lobe was into both the right and the left hepatic duct systems. In 15 per cent the caudate ducts drained entirely into the left hepatic duct or its tributaries and in 7 per cent entirely into the right hepatic duct system.

Specifically considered, then, the duct of the caudate process usually (85 per cent) drained into the right hepatic duct system, and the duct of the left part of the caudate lobe proper in most instances (93 per cent) drained into the left hepatic duct system. Since the right part of the caudate lobe proper is intermediate in position, its ducts may enter either into the left (48 per cent) or the right (52 per cent) hepatic duct system.

Anastomosis of the Right and the Left Bile Ducts. Despite the fact that the ducts of the caudate lobe predominantly (78 per cent) empty into both the right and the left hepatic duct systems, in the casts made by Healey and Schroy there is no evidence of a communication between the bile ducts of the right and the left lobes, even in the caudate region, as claimed by Kiernan (1833) and more recently by Longmire (1948), but denied by McIndoe and Counsellor (1927) for man. Stewart, Cantarow and Morgan (1923) found no evidence for such anastomosis in cats following partial obstruction, nor did Schalm (1951) see any evidence of it after prolonged obstruction offering clinical evidence to substantiate his findings.

Subvesicular Accessory Bile Duct. This filamentlike accessory bile duct lying superficially in the gallbladder bed was described in detail by Haberland of Germany in 1926, who made a thorough study of the surgical anatomy of the bile passageways and who *regarded the subvesicular duct* as a constant phenomenon. In the present author's extrahepatic dissections of 200 bodies this filamentous subvesicular duct was encountered repeatedly (Figs. 59, 71, 74, 77). In the plastic casts of Healey and Schroy (1953) it occurred in 35 per cent and was *not accompanied by a* portal vein, although in 5 per cent it was accompanied by a branch of the right hepatic artery. *In roentgenograms, this subvesical duct is often clearly visible,*

A thousand spleens bear her a thousand ways
She treads the path that she untreads again
Her more than haste is mated with delays
Like the proceedings of a drunken brain
Full of respects yet not at all respecting
In hand with all things nought at all effecting
—WILLIAM SHAKESPEARE Venus and Adonis Verse 152

8

The Spleen, the Splenic Artery and the Intrasplenic (Separatory) Circulation

Anatomico-surgical Considerations

A knowledge of the variational anatomy of the spleen and its blood vessels and a thorough appreciation of the regional vasculature whereby collateral circulation may be established are of fundamental importance especially to the surgeon Such knowledge cannot be gained from the conventional textbook description and illustrations of splenic vascularization All texts of anatomy including those of foreign languages follow a fairly uniform pattern in illustrating the vascularization of the spleen No text calls attention to the fact that each spleen has its own peculiar pattern of terminal branching of the splenic artery (Michels 1912) nor is the diverse configuration of the splenic vein (Douglass Baggenstoss Hollinshead 1950) sufficiently emphasized

Knowledge of the variational anatomy of the spleen especially of its hilus is indispensable to the surgeon in splenectomy resections of tumors and extirpation of cysts for with the best of technic and experience bleeding often occurs with resultant unnecessary death the operative mortality in cases of marked perisplenic adhesions being very high (72 per cent Henschen 1928) In cases where the spleen cannot be removed remedial effects are sought by ligation of the artery leaving the vein open to remove waste products The ligation is practiced in thrombopenic purpura (v Stubenrauch 1929 Lemaire and Debaisieux see van Coidsenhoven 1927) in pernicious anemia (Troell 1916) in hemolytic icterus in selected cases of portal hypertension and in Banti s syndrome (Everson and Cole 1948 Blain and Blain 1950) in inoperable neoplastic syphilitic angiomatous splenomegalies in nonsuturable cases of traumatic or spontaneous ruptures and inoperable wandering spleens Most recently along with the hepatic the splenic is being ligated in the treatment of intrahepatic portal hypertension (Rienhoff 1951)

Since the aim of ligation of the splenic artery in most instances is to effect a simple aseptic necrosis of the spleen (that is to render the organ oligemic and not ischemic) the surgeon should know the significance of his points of ligation This warning applies not only to the splenic artery but also to the splenic vein as well for its tributaries are anatomically different (Douglass et al 1950) and may not lend themselves to a shunting of the portal blood flow in operative procedures to reduce hyper

biliary tree Healey and Schroy make the following comment

In our description of the segments of the right lobe we distinguished two segments (anterior and posterior) in contrast to *Hjortsjo* who described three segments He distinguished a dorsocaudal segment (our posterior) an intermediate and a ventrocranial segment The latter two are *included in our anterior segment* As previously mentioned our segment ducts are the second order of branching (the first order being the right and left hepatic *ducts*) and our area ducts are the third order ducts The ducts draining that region of the right lobe which Hjortsjo called the ventrocranial segment are actually *ducts of the fourth order* (*branches of* either the anterior inferior or the anterior superior area ducts) and therefore in our opinion the region drained by them should not be considered as a *separate segment* He described the right hepatic duct however as being formed by two tributaries which would be equivalent *to our anterior* and posterior segment ducts

Fainsinger (1950) described varying modes of formation of the right hepatic duct the latter being regarded as *bifur*cating trifurcating or undergoing two successive bifurcations Many of his observations were made from cholangiograms without the aid of corrosion specimens Because of the overlapping of the anterior and posterior segment ducts in many cholangiograms the interpretation of the formation of the right hepatic duct by this method alone in such a limited series of specimens is very difficult and likely to be erroneous (*Arch Surg* 66 599 1953)

In regard to the biliary drainage of the left lobe the authors state

Previous investigators (Rex Melnikoff Hjortsjo Fainsinger) are in accord in their descriptions of the two main ducts of the lateral segment differing only in the terminology used The superior and inferior ducts draining the lateral segment of the left lobe showed little variation in their prevailing pattern except as regards the late union of the two area ducts previously mentioned Hjortsjo described the two areas as separate segments designating the superior area the dorsolateral segment and the inferior area the ventrolateral segment The ducts draining these regions however are third order ducts whereas in our work we maintain that segments of the liver are drained by second order ducts (*Arch Surg* 66 599 1953)

As a conclusion the author suggests that every anatomic department should have at least a dozen vinyl acetate casts of the human liver for instructive purposes Human livers are readily available in any medical school and the technic of making a cast of the bile ducts the arteries and the veins in differently colored plastic material is readily learned and executed, albeit the production at the Daniel Baugh Institute of Anatomy of 150 plastic casts of human liver by Healey and Schroy was indeed a formidable task but well worth while in view of the information obtained For this reason no doubt their work was awarded the Certificate of Merit by the American Medical Association at its annual meeting in New York City in 1953

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system will reduce tension. To this effect various veins of the portal system (splenic, superior mesenteric, portal vein itself) *have in recent years been joined* surgically to veins of the inferior caval system. Douglass, Baggenstoss and Hollinshead (1950) in their study of the variational anatomy of the portal vein and its tributaries in 92 specimens emphasize the point that when portal obstruction is extrahepatic only those veins are suitable for the shunting procedure whose junctions with the splenoportal vein are distal to the point of obstruction.

Peculiarities of the Splenic Artery

Among these may be listed:

1. Its large size as compared with the volume mass supplied (diameter 6 to 7 mm., Testut, Henschen). The liver is five times as large as the spleen, yet its artery is smaller in caliber.

2. The branches of the splenic artery as compared with the stem are wider than in any other artery. Roloff, a pupil of Haller (1750), gave a ratio of lumina differences of 25:16.

3. Branches of the artery usually arise at right angles from the stem; in the spleen branching is dichotomic (Sommering). Cremsius (eighteenth-century anatomist) counted 1,000 splenic arteries. Mall calculated 500 million arterial endings by radiographic injections. Henschen distinguished 1 to 10 main arterial zones. The arteries are usually regarded as end arteries in the sense of Cohnheim—i.e., they do not anastomose with one another except at the hilus periphery through intraorganic transversals (Volkmann, 1923). However, Melnikoff (1923) maintained that there is ample anastomosis of the arteries in the spleen, thus allowing for extensive intraorganic collateral circulation.

4. The coats of the splenic artery are usually thick and firm (elastic muscular); those of the splenic vein are unusually thin, weak and distensible, the proportion between the two being as 1,336:1,000 (Winteringham). The artery may withstand a pressure of 11 pounds. The expanding power of the splenic vein is necessary for sudden outpourings of the blood from the spleen (single contraction, 10 per cent of the organ's content), for the venous pendulous circulation between the spleen and the liver, to release overpressure in the portal vein through the spleen. The splenic vein may rupture with excessive exercise. It has no valves and in the pancreas has for the most part only endothelial lining. Rhythmic contractions of the overlying splenic artery impel the blood in the splenic vein.

5. Tortuosity or serpentine course which the artery often shows, the convex side of the twist being stronger and thicker than the concave side (Thoma). Because of the tortuosity the artery may be twice as long as need be (16 cm. instead of 8 cm.). The phenomenon of tortuosity was first observed by J. Caesar Arantius (1751), regarded as the discoverer of the splenic artery. It was known to the artist Leonardo da Vinci.

6. Different modes of origin of the splenic trunk, variable number, different modes of origin and distribution and different calibers of splenic branches, especially those going to the spleen.

7. The varied topography of the artery: Suprapancreatic 90 per cent, retropancreatic 8 per cent, prepancreatic 3 per cent (Henschen), intrapancreatic occasionally.

8. The near and the far reaching collateral arterial circulation, the latter being so extensive that they may replace the entire system of splenic arteries. As will be shown later, there are at least three collateral pathways inside the system of the splenic artery and six outside the system.

tension Furthermore pre existing post caval shunts may be present, as shown recently by Madden (1952)

The importance of a primary ligation of the splenic artery as an aid to surgical mobilization of the spleen, recently has been emphasized *in a film by Philip* Thorek of the University of Illinois (1952) In resections of the spleen and in incisions thereof cognizance must always be taken of the outer and the inner hilus transversal arteries that run in a craniocaudad direction between the branches of the splenic artery as first emphasized by Henschen of Switzerland (1928) in his classical contribution on the anatomy of the splenic artery and the spleen and in an article written with Reissinger (1928) on the clinical physiology of the spleen

Surgical dangers in splenectomies as listed by Henschen comprise (1) Necrosis and perforation of the stomach wall by establishing too short a stem (*left gastro epiploic cut*) *thrombosis* be cause of an inadequate anatomy of the short gastrics (2) Necrosis of the pancreatic tail by including a part of it in the ligature thrombosis in the portal vein postoperative hemorrhagic pancreatitis fat necrosis cysts and fistulization through ligation of important pancreatic rami of the splenic (3) Post operative venous thrombosis in the portal system with infarct necrosis and *perforation of the gut* (4) *Injuries to the* arteries of the colon danger in tying off the middle colic with necrosis of the colon The surgical troubles of the spleen are reviewed by Reid (1954)

Surgical dangers in operative procedures to relieve hypertension (splenorenal anastomosis) as summarized by Douglass et al of Minnesota University comprise (1) difficulty in mobilization of the splenic vein for 8 cm or more when its posterior aspect is covered with pancreatic tissue (2) ligation of the pancreatic veins which should be accomplished individually (3) ligation of the splenic pedicle may endanger the left gastro-epiploic vein (4) the coronary vein *may terminate into the splenic* (16 7 per cent) (5) the superior pancreaticoduodenal vein the pyloric vein *and the coronary* vein may be ligated or injured in manipulation of the portal vein

No other artery in the body is subject to greater sudden hemodynamic alterations than the splenic artery Repeated sudden closures of afferent arterial blood vessels *repeated contractions* and expansions of the organ during exercise repeated refluxes through physiologic and pathologic stasis in the vein tend to throw the splenic artery into a tortuous course a compensatory phenomenon whereby the circulation is made indirect and less forceful *thereby* protecting the soft pulp part of the interior of the spleen from the sudden brutal onrushings of the blood (Neugebauer)

Excessive use of the mechanism of the arterial wall (elastic muscular tissue) results in atrophy calcification sclerosis (even in children) fatty degeneration fat infiltration hyaline degeneration of muscles swelling of elastic tissue and single and multiple aneurysm of the artery while in the vein excessive stretching may lead to spontaneous rupture of its markedly thin wall The contention that the spleen is the main defense *mechanism versus infection* (*Perla and* Marmorston 1935) is paralleled by the equally important contention that the spleen together with the hepatolienal part of the portal system *is a regulator* of the blood stream and that it is this mechanism which in many instances is involved in hypertension (Henschen)

Since the pressure of blood in *the* portal system is 8 to 12 cm of water approximating the tension of *blood in* the systemic veins it is reasonable to conclude that in portal hypertension a shunting of the portal flow into the caval

lobes Marsupials have a flat long and narrow spleen the distal end often being split Higher mammals have a compact nonlobulated spleen although there are some exceptions to the latter statement In rodents the spleen is long and thin in Insectivora narrow and often bent In sheep it is thick and short in horse it is sickle shaped In pig cat and dog it is long that of cat having a spade shaped caudal pole

Internal Structure The amazing variations in the external anatomic configuration and in the topographic position of the spleen in the animal kingdom are duplicated if not exceeded by the extremely varied character of the internal structure in different animals Microscopic variational patterns exist as regards the relative proportion of red pulp and lymphoid tissue (lymphoid sheath and nodular formations) presence or absence of sinuses mode of their formation and character length and character of the penicilli patterns of ellipsoid and ampulla types of follicular capillaries along with striking variations in the structure the amount the disposition and the content of the trabecular framework (See Osogoe of Japan 1954)

Phylogenetically considered not all spleens are constructed alike nor do all spleens function alike *The century old* debate as to the nature of the intermediary circulation in the spleen (i e pathways from the arterial to the venous side along with the question of an open or closed circulation) is due in large measure to the fact that authors on the basis of investigative work on a few species of animals have theorized for a uniform concept of splenic circulation when actually no such uniformity exists One need only examine the spleen of a guinea pig and compare it with that of man to realize that one is treading on different paths and that what holds functionally in one need not hold in the other In guinea pig the lymphoid sheath (white pulp and its reticulum) begins immediately around the arteries and is continuous as shown by Downey and Weidenreich (1911) and more recently with a reconstruction method by Snook (1944)

Nearly a century ago Billroth (1861) spoke of the cavernose Milzvenensinus and showed that structurally considered there are two kinds of mammalian spleens (1) those in which the red pulp is a cavernous plexus of venous sinuses separated by narrow zones of reticular tissue or pulp cords (man rabbit) (2) those in which there is an abundance of reticulum with a few nonanastomosing veins (pig horse cattle) A comparable grouping of spleens was made by Brannwarth (1891) Hoyer (1893) Schumacher (1900) Neubert (1922) Robinson (1930) and Snook (1950) In his classical study of the reticulum of the spleen and on capillaren Milzvenen Mollier (1911) distinguished two types of *splenic capillaries—those with regu*larly and those with irregularly arranged walls MacNeal Otani and Patterson (1927) distinguished three types of arterial splenic capillaries (1) follicular (2) centripetal (3) postellipsoidal to which Jager (1929) has added a fourth type the Hofarterien which as branches of the follicular arteries *curve around the circumference of the* nodule to terminate within the marginal zone

Varied indeed in different animals is the structure of the ellipsoid (periarterial sheath) Schweigger Seidel (1863) was the first to make a comparative study of the length and the width of these structures in various mammals and noted that in man they averaged $53\mu \times 22\mu$ while in cat they were twice that size $100\mu \times 46\mu$ He suggested that they may function as an infiltration apparatus (in cat) and stated that they need not be present on all penicilli According to Riedel (1932) ellipsoid sheaths are well developed in cat dog and pig smaller in horse and cattle small and indistinct

9 The absence of a phylogenetic definite evolutionary pattern of the spleen and the splenic artery (Schabadasch 1935) and the initial protracted association of the splenic anlage with the venous system the arterial supply growing in later (Laguesse 1890 Choronshitzky 1900 Danchakoff 1916 Janosik 1922 Ono 1931) Thiel and Downey (1921) found the earliest vessels to be arterioles

10 The alleged absence of typical capillaries in the spleen and the various passageways which the blood may take in the organ from the arterial to the venous circulation (a) Open circulation through reticular spaces (interstices) in the pulp which lead into venous sinuses —Henle Laguesse Sabin Thiel and Downey Barta (1926) Hueck (1928) Ono (1930) (b) Anatomically closed circulation through a capillary system in the pulp (Billroth 1862 Von Schumacher 1899 Toldt 1879 Helly 1902 Mall Sabin Barthia 1926) (c) A partly closed and partly open system some of the blood running through definite channels (sinuses) other blood through the reticular spaces (Weidenreich Mall) (d) A partly open system effected by pores in the venous sinuses (Mollier Jolly Mall) (e) Neither an open nor a closed system but one consisting of preformed interconnected intactly lined channels the functional control of which is regulated by afferent and efferent sphincters as first proposed by Knisely (1936) categorically denied by MacKenzie Whipple and Wintersteiner (1941) and reaffirmed by Peck and Hoerr (1951) Palm (1951) and Nakata of Japan (1952 1954) in studies of living mammalian spleens transilluminated by the fused quartz rod technic

Comparative Anatomy of the Spleen and the Splenic Artery

Comparative Anatomy of the Spleen

Histogenetically and from the point of view of comparative anatomy the spleen represents a derivative of the lymphatic apparatus of the entire gut Since phylogenetically considered the entire dorsal mesogastrium has the potency of forming splenic anlagen the spleen may be located at the stomach the pylorus the foregut the midgut the hindgut and the omentum while microscopic islets of splenic tissue may be found in the pancreas (Haberer 1901) Absent in *Amphioxus*, the spleen is present in all vertebrates except the cyclostomes The latter have a cavernous spleenlike tissue in the subserous spiroid fold of the midgut and the foregut (Mawas Jordan and Speidel) In bony fishes the spleen is lobulated in other fish families it is compact In the lamprey (*Petromyzon*) it occurs only in the larval stage while in the hagfish (*Myxinae*) it is found in the adult life (Klemperer) Beginning with Amphibia the spleen becomes an isolated and a compact organ In the tailed amphibian *Proteus*, it is long in *Siren lacertina*, it extends along the entire gut In *Anura* it is at the hindgut in *Urodela*, at the stomach In the latter two types the spleen is the main seat of erythropoiesis (Maximow Jordan and Speidel) as it is in certain fishes In ancestral reptilian form of Mynchocephalidae the spleen is long extending from the foregut to the hindgut In the turtle it is associated with the descending colon In the lizard *Lacerta*, the spleen is at the stomach Snakes have a very small spleen at the pylorus In birds the spleen is small round or cylindrical and is located always at the caudal extremity of the foregut

The mammalian spleen exhibits decided variations in size and form but the location is always in the dorsal mesogastrium except in marsupials where a ventral lobe supplements the dorsal lobe The egg laying mammals (Monotremata) possess a primitive reptilian like type of spleen In the spiny anteater echidna and in the duckbill (*Ornithorhynchus*) the spleen consists of three or more

plied. To this group belong rat, dog, cat, hedgehog, monkey and man. In horse the splenic artery does not send a large branch to the pancreas. The lienal artery in horse represents a typical a. curvaturae majoris ventriculi, which gives branches to the spleen, the stomach and the great omentum. Schabadash concludes that (1) there is no definite evolutionary pattern of the spleen or of its blood supply and (2) the architecture of the spleen is determined by hemodynamic laws, i.e., by the amount of blood going to the organ.

The Splenic Artery in Man (100 Dissections)

The splenic (lienal) artery is the largest branch of the celiac, this despite the fact that the spleen is five to six times smaller than the liver. When the three arteries (left gastric, lienal and hepatic) arise from the same point, a tripod celiac is formed (25 per cent, Fig. 58). At times a fourth artery, the dorsal pancreatic or middle colic, arises from the same point, forming a tetrapod celiac (5 per cent, Figs. 10, 80). Occasionally the splenic arises directly from the aorta (Fig. 93) or from the superior mesenteric (Fig. 67). In rare instances it is double (2 cases in 500 bodies), the upper splenic being much smaller (Fig. 51).

In length the splenic artery varies from 8 to 32 cm. (average 13 cm.), the excessive length being due to the fact that the artery is often markedly tortuous, looped and coiled, this condition being maximal in aged individuals (70 to 90), minimal in young individuals (below 40) and absent in infants and in children. The width of the splenic varies from 5 to 12 mm., the artery often having a diameter much larger than that of the hepatic. The ultimate and the penultimate divisional patterns of the splenic artery are never the same. The number of branches entering the spleen vary from 3 to 35. They usually arise at right angles to the stem and, as compared with the latter, are much wider than the branches of any other artery.

Origin. Typically the splenic arises from the celiac via a hepatolienogastric trunk (82 per cent), the most common *form of which is the one in which the* left gastric arises as the first branch, the hepatic and the splenic coming from a common stem (Fig. 61). When the left gastric arises from the aorta, the splenic usually arises along with the hepatic in a hepatolienal trunk (Fig. 73). When the hepatic has a separate origin from the aorta or the superior mesenteric, the splenic usually arises in conjunction with the left gastric, forming a lienogastric trunk (Fig. 93). When the celiac has but two branches (viz., the left gastric and the hepatic), the splenic, as a rule, is derived from the superior mesenteric, forming a lienomesenteric trunk (Fig. 67).

Anomalies. The splenic may arise directly from the aorta, the superior mesenteric, the middle colic, the left gastric, the left hepatic, the right hepatic or the

Width of the Splenic Artery in 100 Bodies

Width in mm.	5	6	7	8	9	10	11	12
Times	5	14	32	19	17	8	4	1

Length of the Splenic Artery (Up to Its Division into Superior and Inferior Terminal Arteries) in 50 Bodies

Length in cm.	8–9	10–11	12–13	14–15	16–22	32
Times	7	15	11	7	9	1

in man very indistinct in mouse rat and guinea pig and absent in rabbit Watzka (1937) found ellipsoids to be well developed in pig dog cat and hedgehog poorly developed and indistinct in man horse sheep and guinea pig Snook (1950) found giant sized ellipsoids in mole but in mouse, rat and guinea pig he could not confirm the existence of ellipsoids nor did he find any evidence for a correlation of the size of the ellipsoid with the splenic musculature as claimed by Riedel (1932) and Watzka (1937)

Snook of Tulane University School of Medicine (1950) studied a large series of mammalian spleens by means of the graphic reconstruction method from serial sections impregnated for reticulum by a modified Bielschowsky method On the basis of his findings with this technic he classified the mammalian spleens into two groups (1) sinusal in which the red pulp contains an elaborate anastomosing plexus of true sinuses (rat guinea pig rabbit dog man squirrel skunk) (2) nonsinusal in which the red pulp contains relatively few branched primordial veins that lead from the pulp meshes into collecting veins (mouse mole cat horse cow pig weasel bat) Snook calls attention to the danger of drawing sweeping conclusions from observations on spleens of diverse animal groups a point to be remembered in clinical application of results obtained from animal experimentation

Snook s classification of mammalian spleens is shown in Table 8

Comparative Anatomy of the Splenic Artery

The nonuniformity in position, size and form of the spleen in the animal kingdom is equated by the nonuniformity of its blood supply Schabadash (1935) made a phylogenetic study of the splenic artery and its branches in fish Amphibia reptiles birds and mammals a total of 255 animals being examined Injections of colored gelatin were used to delineate the vessels The mammals investigated comprised hedgehog dog cat rabbit guinea pig rat horse pig calf monkey and man He maintained that the key of evolution in no way can be used to explain the marked differences existing in the size and the form of the spleen and its type of vascularization The splenic artery of nonmammals (fish Amphibia reptiles and birds) is not homologous with that of mammals It is simple and in many instances represents branches of larger regional arteries—e g a coeliaca coel mes gastrica In mammals the splenic artery becomes changed into a large vessel which serves many organs the magistral type occurring in those animals in which the main trunk and the branches of the splenic artery supply three organs (stomach spleen and great omentum) the distributed type occurring in animals in which a fourth organ (pancreas) is sup-

Table 8 —Classification of Spleens Based on the Nature of the Vascular Channels in the Red Pulp*

I *Sinusal* (having sinuses)		II *Nonsinusal* (having primordial veins)	
A Without penicillar ellipsoids		A Without penicillar ellipsoids	
1 Rat		1 Mouse	
2 Guinea pig		B With penicillar ellipsoids	
3 Rabbit		1 Mole	5 Pig
B With penicillar ellipsoids		2 Cat	6 Weasel
1 Dog	3 Squirrel	3 Horse	7 Bat
2 Man	4 Skunk	4 Cow	

* *Am J Anat* 87 31 1950

above the pancreas where it is thrown into a counterclockwise descending curve the concavity of which faces upward (Fig 101) Variational patterns are instances in which the first segment of the artery ascends runs directly horizontal or is retropancreatic In order of frequency the first segment gives off (a) the left inferior phrenic (Fig 101), (b) the dorsal pancreatic (a pancreatica dorsalis) a large branch distributed to the dorsal surface of the pancreas in the neck region (Figs 108 110 111 120) (c) the superior polar (Figs 103 109) (d) the cardio esophageal (ramus esophagogastricus posterior ascendens) a long slender (1 mm wide) branch running to the cardiac end of the stomach (Figs 115 133) (e) an accessory gastric (Fig 121) or hepatic (f) the inferior mesenteric

2 Pancreatic Segment This portion is prevailingly suprapancreatic (Fig 101) It may be retropancreatic (Fig 117) intrapancreatic (Fig 118) or prepancreatic (Fig 106) Usually it is lodged in part or completely in a groove along the superior dorsal surface of the pancreas (Figs 101 105 136) The segment presents the highest degree of tortuosity (Fig 128) It may be undulating (Fig 102) thrown into one or more loops (Figs 103 104) or coiled (Fig 111) It never lies very far from the pancreas because pancreatic branches that emerge from this section of the artery act as guy ropes fastening the splenic artery to the pancreas (Fig 104) The segment is frequently the site of origin of a long superior polar artery either at the level of the main trunk (Fig 101) or at the upper border of a loop or coil (Fig 134) When the left gastro epiploic is given off from this segment the resultant divisional pattern of the splenic artery is usually the distributed type (Fig 128) A characteristic regional branch is the large pancreatic (a pancreatica magna Fig 104) that enters the pancreas at the dorsal superior border then descends to anastomose to the left with the caudal pancreatic to the right with the transverse pancreatic (Fig 131) The cardio-esophageal branch (ramus esophagogastricus posterior ascendens Fig 101) one or more short gastric (fundic) branches (Figs 102 136) or an accessory left gastric (Figs 123 137) may arise from this segment In some instances the second section of this artery is thrown into loops that extend far above the pancreas in an anteroposterior plane some of the loops being in a vertical others in a horizontal plane (Fig 111)

3 Prepancreatic Segment This portion of the splenic artery usually leaves the upper border of the pancreas to run obliquely along its anterior surface (Figs 101 105 117 136) Lienal branching occurs here most commonly and gives rise to the distributed type of splenic vascularization In the majority of instances (80 per cent) the main splenic trunk divides into the arteria terminalis superior and the arteria terminalis inferior (Figs 101 103) Other patterns comprise cases having a third terminal artery the arteria terminalis media (Figs 104 105) cases having only an a terminalis superior (Fig 126) and cases where terminal division of the trunk is atypical (Fig 121) The left gastro epiploic arises over the tail of the pancreas either from the trunk (Figs 101 102) or from the inferior terminal (Figs 103 105) The a polaris superior arises from the splenic trunk (Fig 102) or its upper main branch (Fig 112) Short gastric and omental rami are frequently given off by the splenic terminals (Fig 101) The caudal pancreatic distributed to the tail of the pancreas may arise from the splenic trunk (Figs 117 137) from its superior or inferior terminal divisions (Figs 103 134) or from the left gastro epiploic (Figs 102 119) One or more inferior

common hepatic (Fig 64) Supernumerary branches comprise the left gastric the accessory left gastric the left hepatic the accessory left hepatic the middle colic the inferior mesenteric, the right gastro epiploic and the left inferior phrenic

For the major portion of its course *the splenic artery lies behind the posterior wall of the omental bursa* and is associated intimately with the upper dorsal surface of the pancreas A prominent fold of peritoneum (plica lienalis) is often raised by the distal portion of the artery just as the left gastric raises its peritoneal fold (plica gastropancreatica) and the hepatic its fold (plica hepatopancreatica) as boundaries of the isthmus of the omental bursa On nearing the spleen the splenic artery enters the phrenicolienal (lienorenal) ligament whereby it or its terminal divisions and their branches reach the hilus The splenic crosses in front of the left crus of the diaphragm and the upper end of the left kidney and is placed above the splenic vein which in contrast with the artery is seldom tortuous

After a short or long course the splenic trunk usually (80 per cent) divides into two main branches the arteria terminalis superior (ramus lienogastricus) and the arteria terminalis inferior (ramus lienogastro epiploicus Fig 101) Frequently (20 per cent) a third terminal the arteria terminalis media is given off (Fig 104) its designation however is at times difficult and arbitrary The terminal splenic branches become subdivided into penultimate and ultimate lienal branches their number (7 to 35) and their manner of entering the spleen (like the branches of the hepatic artery) varying in every instance

The distance of the terminal division point from the spleen is relatively constant (2 to 6 cm) it usually being 3 to 5 cm In contrast with this other lienal branches of the spleen may arise 1 to 12 cm from the hilus—i e anywhere from the celiac axis to the hilus of the spleen

Morphologically considered there are *two types of splenic artery, the magistral* and the *distributed* In the *magistral type* (30 per cent) lienal branching of the main splenic trunk takes place near the spleen (1 to 2 cm from the hilus) in *the distal fourth* or prehilar segment of the artery between the tail of the pancreas and the hilus of the spleen (Figs 116 125 129) In the *distributed type* of splenic artery (70 per cent) branching takes place earlier usually in the second or the third segment (pancreatic pre pancreatic segment Figs 111 120) The magistral splenic artery supplies a *compact spleen* which has even borders and a narrow hilus (Fig 125) the distributed splenic proceeds to a spleen which is *highly notched* at its anterior border has a prominent superior tubercle a thumblike inferior lobe and a distributed hilus (Fig 130)

Previous to breaking up into its two main terminal branches the splenic artery in addition to its constant pancreatic branches may give rise to (1) an accessory left gastric distributed anteriorly or posteriorly to the cardio esophageal region of the stomach (Fig 104) (2) a superior polar artery which accompanied by a vein enters the upper pole of the spleen often through a tubercle (Fig 101) (3) the left gastro-epiploic which in its descent to the greater curvature of the stomach often gives off 1 to 3 inferior polar arteries to the lower pole of the spleen (Fig 105)

Course and Segments of the Splenic Artery As a rule (60 per cent) the splenic artery arises from the celiac to the right of the midline thus necessitating a crossing of *the aorta to reach* the spleen In its course to the spleen the splenic artery may be divided into four segments

I Suprapancreatic Segment It is *very short (1 to 3 cm)* and usually lies

above the pancreas where it is thrown into a counterclockwise descending curve the concavity of which faces upward (Fig 101) Variational patterns are instances in which the first segment of the artery ascends runs directly horizontal or is retropancreatic In order of frequency the first segment gives off (a) the left inferior phrenic (Fig 101) (b) the dorsal pancreatic (a pancreatica dorsalis) a large branch distributed to the dorsal surface of the pancreas in the neck region (Figs 108 110 114 120) (c) the superior polar (Figs 103 109) (d) the cardio esophageal (ramus esophagogastricus posterior ascendens) a long slender (1 mm wide) branch running to the cardiac end of the stomach (Figs 115 133) (e) an accessory gastric (Fig 124) or hepatic (f) the inferior mesenteric

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polar arteries arise in this region from either the trunk or its primary division (Figs 119 130 134)

4 PREHILAR SEGMENT As implied by the term the prehilar division is that portion of the splenic artery situated between the tail of the pancreas and the hilus of the spleen Its lienal branching into the superior and the inferior terminals occurs in this region (1 to 2 cm from the hilus) The resultant arterial pattern is the magistral type (Figs 135 140) that is less frequent (30 per cent) than the distributed type (70 per cent) In the majority of instances the prehilar segment is occupied by penultimate and ultimate lienal branches (Figs 101 105)

Branches of the Splenic Artery The more constant branches of the splenic artery are (1) the pancreatic (2) the superior and the inferior terminals and their penultimate and ultimate branches (3) the short gastrics (vasa brevia) (4) the left gastro epiploic Inconstant yet frequent branches are superior and inferior polar arteries to the spleen and an accessory left gastric of which there are two types one distributed to the cardio esophageal region of the stomach posteriorly (ramus esophagogastricus posterior ascendens) the other distributed to the same region anteriorly The superior polar artery to the spleen is often long and slender and undetected readily may be torn in splenectomies with resultant fatal bleeding (W Mayo) It arises anywhere along the splenic trunk and may spring from the celiac in which case it functions as an arteria splenica secunda (Fig 51)

1 THE PANCREATIC BRANCHES (rr pancreatici) These arise from the splenic at varying intervals as it courses along the upper margin of the pancreas and are for the most part small and vary in number (2 3 5 7) Three of the pancreatic rami however have a relative extensive distribution These are (a) the dorsal pancreatic (a pancreatica dorsalis or the superior pancreatic of Testut) with its large left transverse pancreatic branch (a pancreatica transversa) (b) the arteria pancreatica magna (c) the a caudae pancreatis

a *The dorsal pancreatic*, 1 to 4 mm in width is a *generally unknown yet very important artery Failure to describe it in texts of anatomy and surgery undoubtedly is due to its varied origin* Statistically considered it may arise from the first part of the splenic (40 per cent) or the first part of the hepatic (12 per cent) from the celiac (22 per cent) from the superior mesenteric (14 per cent) or from the aorta (Figs 71 48, 61 57) In some instances (4 per cent) it is the *middle colic or an accessory middle colic, the artery then functioning as both the dorsal pancreatic and the middle colic* (Fig 40) The dorsal pancreatic is distributed mainly to the dorsal surface of the pancreas in the neck region but it may send branches to the anterior surface as well It may readily be found dorsal to the point where the splenic vein joins the superior mesenteric to form the portal vein (Fig 61)

Typically the dorsal pancreatic has two right branches one of these joins the superior pancreaticoduodenal the gastroduodenal or the right gastro epiploic the other supplies the uncinate process of the pancreas which it reaches by passing under the superior mesenteric vein Its characteristic left branch is the transverse pancreatic which courses along the inferior (caudodorsal) surface of the pancreas at the tail end of which it anastomoses profusely with the a pancreatica magna derived from the splenic and with the caudal pancreatic artery derived from the splenic terminal or the left gastro epiploic (Fig 48)

A fourth branch of the dorsal pancreatic artery often descends below the inferior border of the pancreas behind the splenic vein to communicate with the superior mesenteric or with one of its

branches (jejunal middle colic or accessory middle colic) thereby constituting an important longitudinal collateral pathway between the celiac artery and the superior mesenteric artery (Fig 69)

In some instances this descending branch (4 mm) is actually the middle colic or an accessory middle colic (artery of Riolan) which arises from the celiac and in its downward course behind the splenic vein gives rise to a pancreatic branch corresponding and functioning as the dorsal pancreatic (Fig 11)

The site of origin of the dorsal pancreatic should be known to every surgeon operating on the pancreas especially when performing a pancreaticoduodenal resection for carcinoma of the head of the pancreas If extirpation of the pancreas is effected beyond the midline i e to the left of the aorta the dorsal pancreatic is in danger of being severed The remaining part of the body of the pancreas and its tail will be left thereafter to the circulatory efficiency of the a pancreatica magna and to minor pancreatic twigs from the splenic (including the caudal pancreatic artery) as to whether or not sufficient collateral circulation will be re established to prevent ischemic necrosis of the remaining portion of the pancreas

b *The a pancreatica magna of Haller* This is the largest pancreatic branch of the splenic and arises from the distal third of the artery usually from a portion of the artery embedded in the pancreas or from a looped part thereof which has risen above the pancreas (Figs 101 130) The bulky irregularly contoured artery (2 to 4 mm) after entering the pancreas courses obliquely for a short distance from right to left then becomes subdivided into multiple branches some of which course to the right to unite with branches of the transverse pancreatic and with twiglike branches of the splenic other branches course to the left to unite with the a caudae pancreatis derived from the splenic or its branches Since the a pancreatica magna is the main blood supply to the tail of the pancreas it should be spared in operative procedure of this region whenever possible

c *The a caudae pancreatis* The caudal pancreatic artery is a branch which arises from the distal end of the splenic trunk from its terminals or from the left gastro epiploic (Figs 137 111 116) It enters the tail of the pancreas where it communicates with branches from the transverse pancreatic and with those from the a pancreatica magna When the tail of the pancreas touches the spleen (30 per cent) the artery is very short In some instances it is double one arising from the splenic trunk the other from a splenic terminal A pea sized accessory spleen located in the pancreaticolienal ligament may receive its blood supply from a branch of the caudal pancreatic artery (Fig 101) In ligation of the splenic arterial trunk the caudal pancreatic may readily be included leading to necrosis of the tail of the pancreas and to cyst formation (Henschen)

The small twiglike pancreatic rami arise from the splenic at various intervals along its course Placed superficial or deep they unite in loop fashion with twiglike branches from the splenic with branches from the dorsal pancreatic the transverse pancreatic and a pancreatica magna to the left and the gastroduodenal the supraduodenal the superior pancreaticoduodenal and the right gastro epiploic to the right None of the twiglike pancreatic rami is of sufficient size to re establish a collateral circulation once the dorsal pancreatic or the a pancreatica magna is taken

2 The Superior and the Inferior Splenic Terminals These main large end branches of the splenic artery along with their penultimate (4 to 6) and their ultimate branches (2 to 12) present a different divisional pattern in every in

stance Often a third terminal is formed (Fig 104) All lienal branches reach the spleen by means of the phrenicolienal ligament and most of them enter its gastric surface immediately (1 mm to 1 cm anterior to the intermediate border of the spleen) in different planes In about half of the spleens (60 per cent) the renal surface shows entering arteries Most commonly they constitute crawling branches i e tortuous arteries placed in juxtaposition or fastened to the renal surface to which they give off short ultimate branches (1 to 7 average of 3 Figs 105 109 112 119 133) Lengths of the superior and the inferior terminals vary from 1 to 12 cm a common length being 4 cm In magistral splenic arteries terminal division occurs near (1 to 2 cm) the hilus in the distributed type of splenic artery it occurs 2 to 12 cm *from the hilus* Often the superior terminal is considerably larger and furnishes the main direct blood supply to the spleen (Figs 101 131) This is notably the case when a short superior polar artery takes off from the superior terminal (Figs 112 125) Both terminals of the splenic trunk undergo subdivision into penultimate and ultimate branches (Figs 105 108) These vary in width 0 5 to 3 mm in number 2 to 12 and in length 0 5 to 10 mm those given off most distally being the shortest In most instances 4 to 6 large branches are given off by both terminals The ultimate arteries sink directly into the spleen after their origin from the two primary terminal divisions The penultimate are branches of the terminals that give off further branches (2 to 5) before entering the spleen Dichotomic ultimate branches vary considerably in caliber one being much smaller than the other (Fig 5)

The penultimate and the ultimate branches enter the spleen in different vertical planes that vary in number from 3 to 20 It is seldom that either the superior or the inferior terminal sinks into the substance of the spleen without a previous ultimate branching (Figs 126 102) Subdivision of a main terminal may be absent (Fig 110) simple (Fig 115) or complicated (Fig 101)

The divisional patterns of the inferior terminal are far more complicated than those of the superior terminal since both the left gastro epiploic and the inferior polar arteries frequently take origin from it (Figs 103 105) When the superior terminal is excessively large the inferior terminal is small an added blood supply often coming from the left gastro-epiploic via the lienal inferior polar arteries arising from it (Fig 131) At the hilus the primary branches of the splenic vein are actually behind those of the artery but when the ultimate splenic branches enter the spleen in many *different planes the ultimate* venous branches are often situated among them

3 The Short Gastric or Fundic Branches of the Splenic (aa gastricae breves) These arteries along with the venae breves have intrigued the attention of investigators since the time of *Hippocrates (460?–377? B C)* The teaching of the latter that the venae breves running from the fundus of the stomach to the upper branch of the splenic vein carry water from the stomach to the spleen finds its counterpart in the modern physiologic teaching that the spleen is an important reservoir of the body—to wit that it may store fully 15 per cent of the blood volume mass (Barcroft) In current texts too little attention is paid to these short gastrics They are important in that they supply a major section of the stomach and the abdominal esophagus and in that they serve as an important pathway for collateral circulation after splenectomies

Collectively considered the short gastrics (2 4 6 8 10 in number) may be divided into an upper a middle and a

lower group the upper group being the shortest and the lower group the longest Most of the short gastrics pass from between the folds of the phrenicolienal ligament into those of the gastrolienal ligament to reach the fundus and the cardia of the stomach As seen from the composite illustration of the splenic artery and its branches there are at least 2[illegible] different sites of origin for the short gastrics They may arise from the splenic trunk from the superior polar artery or its branches from the a terminalis superior and inferior and their penultimate and ultimate branches from the inferior polar arteries from the left gastro epiploic and its branches Most commonly they arise from the branches of the arteria terminalis superior and inferior Reaching the cardiac end of the stomach they ramify on its anterior and more profusely on its posterior surface and anastomose with branches of the left gastric the left gastro-epiploic and the left inferior phrenic the latter often giving off branches to the dorsal surface of the abdominal esophagus When an accessory left gastric is present (derived either from the celiac or the splenic or from a replaced or accessory left hepatic) the short gastrics anastomose with branches from these vessels The short gastrics are usually very slender and may readily be missed in splenectomies Their tearing causes hidden and disconcerting bleeding (Reid 1954) Short gastrics nearly invariably are accompanied by small veins exceptions being instances in which single or multiple (1 to 3) veins emerge from the superior pole of the spleen to function as short gastric veins A long superior polar artery often gives rise to 2 to 4 fundic branches Fundic branches from the main splenic trunk may be large in some instances attaining the size of an accessory left gastric

4 The Left Gastro epiploic. This artery usually (72 per cent) arises from the splenic trunk several centimeters (1 to 4) proximal to its primary terminal division (Figs 101, 102 107 120 133) Not infrequently it arises from the inferior terminal or from one of its lienal branches (22 per cent Figs 103 104 108 118) Least frequent is its origin from the middle of the splenic trunk (6 to 7 cm from the spleen Fig 135) or from the superior terminal of the splenic (Fig 113)

The left gastro-epiploic reaches the stomach below the fundus by means of the pancreaticolienal ligament and descends along the left side of the greater curvature in the anterior layer of the great omentum At times adjacent at times far removed (20 mm) from the inferior border of the stomach in the majority of cases (90 per cent) it effects a direct anastomosis with the right gastro epiploic constituting the arcus arteriosus ventriculi inferior of Hyrtl

Surgically considered it is important to know that in many instances (10 per cent) the left gastro epiploic does not anastomose with the right gastro-epiploic at all while in other cases anastomosis is effected meagerly by small arterioles even capillaries Often in the absence of this anastomosis the left gastro-epiploic becomes resolved into numerous small branches which unite with similar branches from the right gastro-epiploic which prevailingly is larger since it supplies a larger section of the greater curvature The left gastro-epiploic may be replaced by two or three vessels the main vessel arising from the splenic artery the other or others from a polar artery given off by the splenic to the spleen Occasionally the left gastro epiploic takes origin from the interior of the spleen (Figs 49 52 55)

Collectively considered the blood volume coming to the spleen from the *lienal branches of the left gastro epiploic* (2 to 4 inferior polars) may approximate that reaching the spleen through its pri

mary lienal branches (Figs 141, 142 145) Like its parent trunk the left gastro epiploic is frequently tortuous *and looped but rarely coiled* Tortuosity may extend to its emerging inferior polar arteries that often lie in loops and spirals *on the gastric surface of the spleen* making the identification of the left gastro epiploic difficult and disconcerting

Branches of the Left Gastro-epiploic These comprise 2 to 4 fundic branches numerous short ascending gastric branches (rami gastrici) to the anterior and the posterior surfaces of the stomach numerous short and long descending epiploic or omental branches (aa epiploicae anteriores) some of which communicate with like branches from the right gastro epiploic and with branches from the left colic pancreatic rami to the tail of the pancreas two or three of which may be small and one large and known as the a caudae pancreatis inferior polar arteries to the spleen which vary in number (1 to 5) size and length and in some instances furnish the blood supply to an accessory spleen located in the pancreaticolienal or the splenocolic ligament (Fig 129)

The most important branch of the left gastro epiploic is the left epiploic (a epiploica sinistra) which forms the left limb of the arcus epiploicus magnus of Barkow *the right limb being formed by* the right epiploic (a epiploica dextra) from the right gastro epiploic or from the transverse pancreatic The arch is usually found in the posterior layer of the great omentum below the transverse colon which it supplies by ascending rami (posterior epiploics) some of which *communicate* with the vasa recta of the middle colic The posterior omental branches (posterior epiploics) reaching the transverse colon are never of sufficient size to take over the blood supply *of the transverse colon* once the middle colic has been severed (Figs 1 100)

Polar Arteries to the Spleen

The frequency of polar arteries to the kidney is well known and can well be explained on an embryologic basis With *the spleen the incidence* of polar arteries is just as frequent although not so apparent as in the kidney The formation *of splenic polar arteries is undoubtedly* correlated with the primitive development and the vascularization of the *spleen the latter having developed* as isolated multiple hillocks of mesenchyme cells as seen by the author as an M A student in the histology slides of Thiel and Downey of the University of Minnesota (1921)

Superior Polar Artery The arteria polaris superior occurred in 65 per cent of the cases studied *Its length varies* from 2 to 12 cm its width from 1 to 5 mm its branches from 2 to 13 Regionally *it may take origin from the first* the second the third or the fourth segments of the lienal artery Most frequently *(75 per cent) it arises from the* main splenic trunk proximal to its primary division (Figs 101 103) less frequently *(20 per cent) from the superior terminal or its branches (Figs 112 125)* and only occasionally from the inferior *terminal (Fig 117) It may* arise separately from the celiac axis thus providing the spleen with a double splenic artery two instances of which were observed in 200 bodies (Figs 51 147) An incomplete arteria lienalis secunda *is* shown in Figure 146 where the superior polar takes origin from a short splenic *trunk (5 cm)* and proceeds *3 cm* to anastomose for a short distance with the parent trunk before reaching the spleen In one instance an a lienalis secunda was formed by a large (5 mm) a pancreatica transversa that took *origin from* the superior mesenteric (Fig 121) Frequently, the superior polar (Fig 111) is very long (10 to 13 cm) slender and threadlike (1 mm) and because of these

facts may readily be missed and torn in splenectomies causing hidden and fatal bleeding is shown by William Mayo (1915) at a postmortem examination of one of his cases To avoid this Henschen suggests that in all splenectomies ligation of splenic branches should be started from the inferior pole of the spleen

Short gastric branches (Fig 101) an accessory left gastric (Fig 123) or the ramus esophagogastricus posterior ascendens (Fig 118) may give off one or more short superior polar arteries Looped and coiled portions of the splenic artery are often the site of origin of a long superior polar (Figs 111 131) When the latter is short and given off by the superior terminal it at times crawls along the junction points of the gastrorenal surfaces giving off numerous short ultimate branches before sinking into the substance of the spleen (Fig 112) Only occasionally does a spleen have both the a polaris superior and the ramus esophagogastricus posterior ascendens (Fig 111) The latter may arise from the left gastric in a common trunk with the left *inferior phrenic then send a* superior polar artery to the spleen It may arise as a branch of the superior polar (Fig 109)

The superior polar exhibits the characteristic *splenic tortuosity (Fig 120) it* branches distally before entering the spleen (Figs 101 102) occasionally sending several branches to the diaphragmatic surface and twigs to the splenic capsule Prevailingly it gives origin to short gastric branches (Fig 101) rarely to the left inferior phrenic (Fig 122) and the pancreatic rami It exhibits anastomosis with the splenic artery *(Fig 146)* and *with the superior* terminal or its ultimate branches (Figs 111 127 131 132 151) The incidence and the caliber of the artery appear to be correlated with tubercle formation for it is most prominent in spleens having large tubercles (Figs 101 109 127)

A tubercle may be served solely by a superior polar that enters its tip through one or more pits (Fig 101) by the superior terminal lodged in a deep groove alongside the tubercle (Fig 129) or in both ways the arteries as a rule anastomosing with each other thereby constituting an arterial ring around the tubercle (Figs 131 134)

Inferior Polar Arteries Polar arteries to the inferior extremity of the spleen are much more numerous (1 to 5) and varied than those running to the upper pole They occurred in 82 per cent of the spleens investigated They may arise directly from the splenic trunk (Figs 124 126 130) from the inferior terminal or its branches (Figs 103 132) or from the left gastro-epiploic (Figs 101 102 103) the latter type being the most frequent Least frequent is an origin from the superior terminal (Fig 138) Inferior polar arteries at times have a multiple origin one from the splenic trunk or its inferior terminal one or more from the left gastro epiploic (Fig 130) As a rule the caliber of the inferior polar artery is smaller than *that of the* superior polar However in some instances it attains the proportion of a primary splenic branch and enters the spleen through its own hilus (Figs 119 132) *The longest* polar arteries (3 to 8 cm) are those from the left gastro epiploic which frequently give off two branches to the spleen (Figs 120 131)

The inferior polar and the left gastro epiploic at times are of such uniform caliber that it is difficult to say whether the inferior polar arises from the left gastro-epiploic or the latter from the former (Figs 111 122) Cases were observed *in* which the caliber of the inferior polar was nearly twice that of the left gastro-epiploic that took origin from it (Fig 145) The inferior polar arteries exhibit tortuosity terminal branching (2 to 4) and in many instances anastomosis with regional arteries (Fig 137)

Tortuosity here is restricted to undulations and looping (Fig 124) coiling being rare Branching is penultimate and ultimate occurs as a rule shortly before the artery reaches the spleen, and is prevailingly dichotomic in many instances one of the branches being smaller than the other (Figs 101 105) The ultimate branches enter the spleen by way of pits or small depressions into which the gastrosplenic ligament extends (Figs 101 103) Often the inferior polar sends a crawling branch to the renal or the colic surface of the spleen the emerging ultimate arterial twigs being short tortuous and numerous (Figs 126 130) These irregular polar twigs are comparable with those distributed to the renal surface from the inferior terminal (Fig 105)

Anastomoses of the inferior polar arteries comprise junction with the inferior terminal or its branches (Figs 136 149) with the left gastro-epiploic and with other polar arteries Two macerated spleens revealed anastomosis of the inferior polar artery with branches of the inferior terminal inside the substance of the spleen If such anastomosis proves to be of generalized occurrence a more adequate explanation for red and white infarcts may be advanced—to wit that a white infarct occurs in the absence of an inferior polar artery anastomosis whereas a red infarct occurs when ample inferior anastomosis is established

A characteristic phenomenon is the selective distribution of inferior polar arteries to notched areas the arteries as a rule being numerically proportional to the notches a common number being 2 (Figs 101 102 105 107 119 137) Just as a tubercle at the superior pole of the spleen often has a superior polar so a thumblike lobe at the inferior pole is prone to have a polar artery (Figs 113 121 124 127) Often deeply notched areas of the spleen are served by a polar artery that divides distally, one branch going above the notch the other below it (Figs 102 105 137) When polarlike arteries run to the center of the spleen near its anterior border they likewise are associated with notched formation (Figs 110 118) Accessory spleens in the gastrosplenic and the phrenicocolic ligaments often receive their blood supply from branches of inferior polar arteries either directly or through their branches (Figs 129 138)

Morphologic Variations of the Spleen
(100 Dissections)

The terminal divisional patterns of the splenic artery are correlated so intimately with the morphologic variations of the spleen especially of its medial surface *that on seeing or feeling the spleen and its hilus the surgeon usually can predict its type of vascularization in the sense that a notched spleen with a wide hilus will have a more complicated type of vascularization than a spleen having even borders and a compact hilus* Allowing for differences in size and form in the living subject the human spleens studied fell into the following groups orange segmentlike 44 per cent tetrahedral 42 per cent triangular 14 per cent In all types the medial surface of the spleen is divided by an intermediate ridge into two fields the gastric and the renal In tetrahedral spleens the intermediate border is subdivided inferiorly into an anterior and a posterior border these serving as boundaries for the colic or the basal surface molded largely by the colon (Figs 103 105)

The splenic surfaces gave the following measurements *gastric* 2 5 to 6 5 cm average 4 cm *renal,* 1 5 to 4 5 cm average 3 cm *diaphragmatic* (a) length 6 to 15 cm average 11 cm (b) width 4 to 11 5 cm average 7 cm *colic* 1 x 6 cm average 2 x 5 cm The intermediate border varied from 4 to 13 mm average 8 mm The thickness of the spleen va

ried with its surfaces At the point of greatest thickness on the gastric surface measurements varied from 2 to 5 cm giving an average of 3 cm Except for the variations in dimensions and contours the diaphragmatic surface had the most uniform morphology It was seldom deeply indented or notched (Figs 124 130 139) and on no occasion vascularized by a lienal branch except for fine twigs from the superior polar that over reached the renal gastric surface (Fig 130)

The diaphragmatic surface showed racial differences in length In blacks it was shorter than in whites thus confirming the observation of Moon (1928 Emeritus Professor of Pathology of the Jefferson Medical College) that small spleens are more frequent in Negroes than in whites

It is quite obvious that these surface measurements on cadaver spleens are not absolutely reliable for it is well known that in the living body the spleen shows decided variations in size (amount of blood content) and form (pressure of neighboring organs) Henschen and Reissinger of Basel Switzerland (1928) demonstrated that the cavernous spleen of a dog may expand 10 to 12 times its empty weight (from 63 to 750 gr) On the other hand it has often been noted that when the stomach is contracted and the colon distended the spleen is tetrahedral whereas when the stomach is filled and the colon empty its form is that of an orange segment Between these two extremes there are many possible intermediate forms

Collectively considered one may distinguish two types of spleens (1) *a compact type* with narrow hilus and even borders (Figs 112 135 140) (2) *a distributed type* with distributed hilus notched anterior border a thumblike lobe at the inferior pole a tubercle at the upper pole (Figs 101 119 127) The types give rise respectively to the following patterns of the lienal artery (1) *Magistral type* (30 per cent) in which the splenic trunk is long terminal division occurs near the hilus branches are few large and enter about one third to one fourth of the medial surface Superior polar arteries are absent or arise from the superior terminal The left gastro epiploic often arises from the inferior terminal (Fig 112) (2) *Distributed type* (70 per cent) in which the splenic trunk is short lienal branching occurs early anywhere from the celiac artery to the hilus branches are more numerous are smaller in caliber and enter three fourths of the medial surface at times being distributed to the entire medial surface in successively placed frontal planes Polar arteries are frequent distributed to upper and lower poles The left gastro-epiploic as a rule arises from the splenic trunk (Fig 120)

Hilus lienis In both types of spleen and arterial pattern branches of the splenic artery as a rule enter the gastric surface immediately (1 mm to 1 cm) anterior to the intermediate border Opposed to the common conception and description the point of vessel entrance —the hilus of the spleen—is extremely variable No other structure in the spleen shows such marked differences in morphology and position In the 50 spleens illustrated 18 have one hilus 23 have two hila the rest have three or four

In most instances there are two hila or depressions one for the superior terminal and one for the inferior terminal (Figs 103 132 133) Variations from this are instances in which the whole gastric surface is vascularized in a more or less continuous line (Fig 106) where the main hilus is situated in the upper (Fig 115) or the lower half of the organ (Fig 104) where the vessel entrance is restricted to one hilus (Fig 113) where there are three distinct hila (Fig 125) or none at all the vessels entering the organ in various planes (Fig 130) Not

Tortuosity here is restricted to undulations and looping (Fig 121) coiling being rare Branching is penultimate and ultimate occurs, as a rule, shortly before the artery reaches the spleen, and is prevailingly dichotomic in many instances one of the branches being smaller than *the other (Figs 101, 105) The ultimate* branches enter the spleen by way of pits or small depressions into which the gastrosplenic ligament extends (Figs 101 105) Often the inferior polar sends a crawling branch to the renal or the colic surface of the spleen the emerging ultimate arterial twigs being short tortuous and numerous (Figs 126 130) These irregular polar twigs are comparable with those distributed to the renal surface from the inferior terminal (Fig 105)

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the *renal surface* showed entering arteries Most commonly they constituted crawling branches — that is tortuous arteries placed in juxtaposition or fastened to the renal surface and giving off short ultimate branches (1 to 7 average 3) They usually emerge from the inferior terminal (Figs 105 109 112 119 133) but may come from an inferior polar (Figs 113 130) a superior polar (Fig 132) the superior or the middle terminal (Figs 105 131) the caudal pancreatic (Fig 107) Occasionally they have their own hilus (Fig 117) Branches to the renal surface often reach the posterior border of the spleen but rarely turn to the diaphragmatic surface (Fig 130) Comparable crawling branches may be found on the colic surface (Figs 126 128)

Tubercles In many spleens the intermediate border (5 to 13 mm wide) extends only to one half or one third the length of the organ the remaining portion being expanded to form a tubercle (Figs 101 116 122) Tubercles vary in length from 2 to 5 cm in breadth from 1 5 to 2 5 cm When large and prominent they usually have their own blood supply most commonly from the superior polar (Figs 101 103) The superior terminal is often lodged in a groove adjacent to the tubercle to which it gives off numerous branches (Figs 114 126) The ventral surface of the tubercle may be supplied by branches from an outer hilar transversal uniting the superior polar and the superior terminal (Fig 131) At times the tubercle is surrounded by an arterial ring formed by the superior polar and the superior terminal the vessels anastomosing (Fig 127) Below the tubercle the intermediate border may have pits for arteries coming directly from the splenic or its branches (Fig 103)

Notch Formation and Vessel Orientation The anterior margin (margo acutus) of the spleen is invariably sharp deflecting in triangular fashion into the diaphragmatic and the gastric surfaces sometimes into the colic It is seldom evenly contoured Usually it presents one or two major notches and several ridges (Figs 101 102) Notches on the anterior margin occurred in 85 per cent of the cases studied They varied in number from 1 to 6 in depth from 1 mm to 4 cm One pronounced notch usually alters the plane of the anterior border (Fig 105) Several notches may render it extremely irregular (Figs 119 126) As a rule the anterior notches extend into the gastric surface more deeply than into the diaphragmatic Even when very deep (2 cm) they rarely reach the center of the gastric surface and on no occasion are they sufficiently numerous and pronounced as to give the spleen a distinctly generalized lobulated appearance as is the case in some of the lower animals (seal lizard) The closest approach in the human spleen to lobule formation is the production of a thumb like lobule at the inferior pole (Figs 113 124 127 138) Such lobules measure 2 x 4 cm protrude from the general plane of the anterior border and have their own blood supply through an inferior polar artery the vessel reaching the lobule in a protracted portion of the gastrosplenic ligament attached to the lobule (Fig 138) An exceptional lobular spleen is shown in Figure 130 Here two anterior notches cut deeply into the gastric and the diaphragmatic surfaces leaving an intermediate lobule with its own blood supply

Notches on the posterior border (margo obtusus) of the spleen were observed in 20 per cent of the cases They were decidedly less marked than those on the anterior border In one case however a posteromedial notch was so deep and wide as to cut the renal surface in two and to indent the diaphragmatic surface to over one half of its diameter (Fig 139) In another instance three

infrequently the gastric surface has a nonvascular hillock (convex elevation) between the two hila resembling conditions in the dog's spleen (Fig 133) In many instances a small (1 cm) accessory spleen is lodged in a depression made by the lower hilus (Fig 133)

The hila as a rule are located in vertical planes and are restricted to the gastric surface They may be crescent shaped (Fig 142) or triangular (Fig 104) In the same spleen one hilus may be deep the other superficial (Fig 110) The lower main splenic branch (a terminalis inferior) may have its hilus on the renal surface (Figs 117 142) A hilus on the renal surface is not only a matter of physiologic alteration of position for ultimate branches of the splenic artery often reach the posterior border (Fig 112) When the tail of the pancreas is in contact with the gastric surface (30 per cent Ssoson Jaroschewitsch) it is usually posterior to a hilus The author has seen it inserted between two hila also deeply telescoped into splenic tissue itself

Although the plane of vessel entrance is posterior to the central longitudinal axis of the gastric surface that is immediately anterior to the intermediate border rarely do the ultimate splenic branches enter the gastric surface in one plane The figures show that the larger the number of ultimate and penultimate branches the larger the number of planes in which the vessels enter the spleen (3 to 20 planes average 7) Thus in the spleen having 21 ultimate branches 10 distinct planes of vessel entrance were noted (Fig 112) whereas in the spleen with 36 ultimate branches 20 distinct planes were counted (Fig 130) The distance between the planes varies from 1 to 10 mm and may be anterior or posterior to the main hilus The primary splenic branches usually enter in a frontal plane the aberrant frequently in a horizontal The length of the line of vessel entrance along the longitudinal axis of the gastric surface likewise shows considerable variations (from 4 to 12 cm average 8 cm) and is conditioned by the morphology of the spleen the compact type having a small vertical line of vessel entrance (Fig 140) the distributed type a large one (Fig 122)

Pits (Foveolae) In addition to the main hilus the gastric surface in the majority of instances presents pits (1 to 15 average 4) or slight depressions in the splenic substance for the entrance of ultimate branches (Figs 105 120 130) Such pits are common in distributed spleens and invariably are associated with the superior and the inferior polar arteries (Figs 101 103) The depth and the size of the pits vary with the caliber of the entering arteries but never attain the character of a distinct hilus The pits may be in the same plane as the main hilus but usually they are anterior or posterior to it Pits occur prevailingly on the gastric surface They have been encountered in the upper and the lower extremities of the spleen (Fig 101) near the anterior border (Fig 108) on the renal and the colic surfaces (Figs 128 147) on the intermediate border (Fig 105) and even on the diaphragmatic surface (Fig 130) In spleens having a thumblike lobule the pits are found in the center of the lobule and on its superior and inferior surfaces (Figs 113 130)

Renal Surface This surface is prevailingly somewhat concave molded thus by the kidney Evenly contoured at the posterior margin it is very irregular at the intermediate border, due to the irregularity of the vessel entrance In many spleens posterior notches make deep indentions (Figs 113 124) Occasionally they bisect the entire renal surface (Figs 127 139) In current texts no mention is made of an arterial blood supply to the renal surface of the spleen yet in 60 per cent of the cases studied

loop often lies in a groove along the upper dorsal surface of the pancreas the organ covering the loop entirely or only in part (Fig 115) Looping or coiling may occur within the pancreas (Fig 10[illegible]) or behind it (Fig 117) Although in these instances the artery is contiguous to the pancreas it is invariably separated from it by a connective tissue membrane Away from the pancreas the artery may show only loops a sequence of loops curves and spirals the last often resting on the spleen Both the ventral (anterior) and the dorsal (posterior) sides of the spirals and the loops may serve as the sites of origin of the a pancreatica magna the a caudae pancreatis the short gastrics the superior polar and the left gastro-epiploic Cases were encountered in which a large section of the splenic artery was rolled into loosely packed spirals and loops these grooving their patterns in the substance of the pancreas from which they were separated by a membrane Circuitous and repeatedly coiled sections of the artery usually are located along the upper margin of the pancreas (Fig 101)

Tortuosity of the splenic artery is not restricted to the main arterial trunk but occurs frequently in the terminals and their penultimate and ultimate lienal branches (Fig 104) The tortuous end vessels are often packed tightly against the gastric surface of the spleen in such irregular fashion that at first sight it is difficult to determine the specific origin of the end branches Commonly the superior polar artery of the spleen is markedly tortuous in instances attaining a full circle twist which may be located anywhere from the artery s origin to its termination The inferior polar and the left gastric arteries show less tortuosity but even in these it may occur in a marked degree (Figs 113 124)

Coiled and looped sections of the splenic artery often show remarkable differences in lumen the afferent side of the loops and the coils having a smaller diameter than that of the efferent side (7 mm versus 9 mm) (Figs 101 111, 131 137) In other instances the reverse is the case (Fig 118) or constriction is limited to both ends of the loop (Fig 103) Extremely long and tortuous splenic arteries may have a diameter considerably larger (12 mm) than the average of the author s series which is 7 5 mm (Fig 105) They may show differences in lumen from their celiac origin to the spleen the celiac itself being varied in diameter (7 mm versus 12 mm) (Fig 128) Comparable differences in lumen exist in a split splenic artery (Figs 131 136) and in the a pancreatica transversa when it serves as an a lienalis secunda (Fig 121) As noted many years ago by Thoma of Germany cross sections of looped portions of tortuous arteries show the convex side of the twist to be *thicker* than the concave this being most probably a mechanical compensatory phenomenon (A long neglected field of research)

Tortuosity of the splenic artery was first described by Julius Caesar Arantius of Vienna (1751)—Arteriae lienis ductum obliquum ac flexuosum anguis in modum primus observavit—(ita Douglas 1754 cit Henschen) As previously stated the phenomenon of the tortuosity of the splenic artery was known to Leonardo da Vinci in the sixteenth century for he made mention of the fact that in old people the splenic artery increases in thickness grows longer and *becomes twisted like a snake Now, nearly 400 years later the cause of the tortuosity of the splenic artery is still unknown* the artery in some instances being three times as long as need be (30 cm instead of 10 cm)

Speculatively considered tortuosity of the splenic artery may be due to (1) Movements and volumetric changes of the spleen the number and the degree of bends in the splenic artery being di

deep notches extended over the diaphragmatic surface the inferior notch nearly severing a lobule from the splenic mass (Fig 127) Occasionally a deep fissure on the diaphragmatic surface connects an anterior and a posterior notch

The cause underlying notch formation is unknown Parsons of England (1901) made a phylogenetic study of the problem and concluded that Notches are mere crumplings of the spleen due to its growth and to the pressure of the surrounding viscera (*Journ Anat & Physiol* 35 416 1901) From a consideration of the development of the spleen as ascertained by Thiel and Downey (1921) and from present observations the author favors an embryonic interpretation and regards notch formation as a *persistence of an embryonic pattern* the notches being correlated with original developmental foci of splenic tissue A developmental history of multiple splenic anlagen each with its own arterial twig adequately accounts for the separate blood supply to tubercles (Figs 101 103 127) and to inferior thumblike lobules (Figs 113 124 127 138) A similar de*velopmental cause may underlie notch* formation and the selective distribution of splenic branches to notched areas The arteries *involved are predominantly* the inferior polars (Figs 101 102 119) Often allotment of arteries to notched areas is in exact numerical agreement that is spleens having two notches have two polar arteries (Figs 105 137) spleens having three notches have three polar arteries (Fig 126) or one polar artery may bifurcate one branch going above one below the notch (Fig 102) In this connection *it is interesting to note that the selective distribution of polar arteries to notched areas in the 25 infants investigated by the author is fully comparable with conditions existing in the adult*

Tortuosity of the Splenic Artery

The most striking characteristic of the splenic artery is its *tortuosity*, that is the irregular, serpentine, circuitous course it prevailingly exhibits Of the splenic arteries investigated 15 per cent were straight 45 per cent were slightly curved and 40 *per cent* were *looped or coiled* Lipshutz (1917), in a study conducted in the same laboratory (Daniel Baugh In*stitute of Anatomy of Jefferson* Medical College), reported tortuosity as being marked and frequent in 67 per cent of 83 bodies slight in 33 per cent Carmel of the University of Pennsylvania Medical School (1925), found the splenic ar*tery to be notably tortuous in only 6 of* 30 cases Henschen, of the Surgical Clinic of the University of Basel, Swit*zerland (1928), states that the splenic* artery is predominantly tortuous

In the splenic arteries studied tortu*osity manifested itself in (1) continuous* irregular serpentine curves (Fig 110) (2) one or more spirals that is full circle twists (Fig 101) (3) one or more (1 to 6) loops or half circle twists (Fig 111) (4) loops and spirals (Fig 122) (5) superimposed coils (Figs 105, 128) Tortuosity was frequent and most pronounced in the second and the third segments of the artery that is in the pancreatic and the prepancreatic segments Here loops of the artery were often festooned to the pancreas by pancreatic branches (Fig 104) that in instances encircled the loops When the artery had 2 to 8 loops some of them were placed in a horizontal plane (dorsal loops of 2 to 4 cm) others in a vertical plane (cephalad loops 2 to 4 cm) resembling in this respect the looped piping of a natural gas line (Fig 128)

In its course to the spleen a tortuous looped spiral artery may follow an anteroposterior plane for 7 cm the plane being at the same time obliquely cephalad (Fig 114) The initial spiral or

loop often lies in a groove along the upper dorsal surface of the pancreas, the organ covering the loop entirely or only in part (Fig. 115). Looping or coiling may occur within the pancreas (Fig. 105) or behind it (Fig. 117). Although in these instances the artery is contiguous to the pancreas, it is invariably separated from it by a connective tissue membrane. Away from the pancreas the artery may show only loops, a sequence of loops, curves and spirals, the last often resting on the spleen. Both the ventral (anterior) and the dorsal (posterior) sides of the spirals and the loops may serve as the sites of origin of the a. pancreatica magna, the a. caudae pancreatis, the short gastrics, the superior polar and the left gastro-epiploic. Cases were encountered in which a large section of the splenic artery was rolled into loosely packed spirals and loops, these grooving their patterns in the substance of the pancreas from which they were separated by a membrane. Circuitous and repeatedly coiled sections of the artery usually are located along the upper margin of the pancreas (Fig. 101).

Tortuosity of the splenic artery is not restricted to the main arterial trunk, but occurs frequently in the terminals and their penultimate and ultimate lienal branches (Fig. 104). The tortuous end vessels are often packed tightly against the gastric surface of the spleen in such irregular fashion that at first sight it is difficult to determine the specific origin of the end branches. Commonly the superior polar artery of the spleen is markedly tortuous, in instances attaining a full circle twist which may be located anywhere from the artery's origin to its termination. The inferior polar and the left gastric arteries show less tortuosity, but even in these it may occur in a marked degree (Figs. 113, 124).

Coiled and looped sections of the splenic artery often show remarkable differences in lumen, the afferent side of the loops and the coils having a smaller diameter than that of the efferent side (7 mm. versus 9 mm.) (Figs. 101, 111, 131, 137). In other instances the reverse is the case (Fig. 118), or constriction is limited to both ends of the loop (Fig. 103). Extremely long and tortuous splenic arteries may have a diameter considerably larger (12 mm.) than the average of the author's series, which is 7.5 mm. (Fig. 105). They may show differences in lumen from their celiac origin to the spleen, the celiac itself being varied in diameter (7 mm. versus 12 mm.) (Fig. 128). Comparable differences in lumen exist in a split splenic artery (Figs. 131, 116) and in the a. pancreatica transversa when it serves as an a. lienalis secunda (Fig. 121). As noted many years ago by Thoma of Germany, cross sections of looped portions of tortuous arteries show the convex side of the twist to be *thicker* than the concave, this being most probably a mechanical compensatory phenomenon. (A long neglected field of research.)

Tortuosity of the splenic artery was first described by Julius Caesar Arantius of Vienna (1751)—"Arteriae lienis ductum obliquum ac flexuosum anguis in modum primus observavit"—(ita Douglas, 1754, cit. Henschen). As previously stated, the phenomenon of the tortuosity of the splenic artery was known to Leonardo da Vinci in the sixteenth century, for he made mention of the fact that in old people the splenic artery increases in thickness, grows longer and *becomes twisted like a snake. Now, nearly 400 years later, the cause of the tortuosity of the splenic artery is still unknown,* the artery in some instances being three times as long as need be (30 cm. instead of 10 cm.).

Speculatively considered, tortuosity of the splenic artery may be due to: (1) Movements and volumetric changes of the spleen, the number and the degree of bends in the splenic artery being di-

rectly proportional to these (2) Pulsating blood flows to the spleen that at first cause excessive stretchings of the artery but ultimately give rise to permanent bends loops and spirals with resultant lengthening of the artery In this sense tortuosity is a compensatory phenomenon—that is the circulation is made indirect and less forceful thereby protecting the soft pulp of the interior of the spleen from the sudden strong onrushings of the blood (Henschen and Reissinger 1928) As a corollary to this concept it follows that variations in diameters of the splenic artery (almost invariably associated with tortuosity) are of *fundamental importance in altering the quantity of blood passing to the spleen for Poiseuille's law states that, with the same pressure, the same temperature and the same length of tube, the quantity of flowing blood is proportional to the square of its diameter* (3) Tortuosity is partly passive The pancreatic branches act as guy ropes allowing portions of the splenic trunk between the pancreatic branches to become tortuous (Henschen) (4) Tortuosity may be a developmental peculiarity correlated with heredity (5) *It may be a diseased* condition due to arteriosclerosis (Lubarsch Carmel 1925)

The present studies being purely morphologic do not solve the problem However they show that tortuosity is *definitely* correlated with the *length* of the splenic artery and with *age* Briefly in splenic arteries of 8 to 11 cm lengths tortuosity was either slight or moderate (Fig 109) in long splenic arteries (13 to 32 cm) it was marked being maximal in the largest splenic artery encountered (*Fig 128*) *Similarly the incidence* and the degree of tortuosity in the terminal lienal branches are associated with their lengths in the sense that the longer the terminal branches the more frequent and the more pronounced the tortuosity (Fig 104) That tortuosity of the splenic artery is correlated with age (that is is a *primary induced effect and one of long* standing) is evident from the fact that it was prevailingly more marked and of greater frequency *in individuals over 50* years of age being maximal in bodies 80 years old (Figs 103 104 111 116 127) and from the fact that, in the 25 infants investigated by the author at the Daniel Baugh Institute of Anatomy of the Jefferson Medical College the splenic artery was not tortuous

The present study lends little support to the contention that tortuosity *is a diseased condition associated with arteriosclerosis* In several bodies showing marked hardening of the splenic artery (arteriosclerosis) loops were encountered that were highly rigid and very brittle a mere attempt to bend the loop resulting in its breaking *In one instance of the 100 bodies studied a "pipe stem splenic artery was observed* (Fig 106) *The two phenomena may, therefore occur simultaneously—a tortuous splenic artery may become stiffened by calcification, but this happens very rarely The relationship was observed only a few times Furthermore, an individual may have died from arteriosclerosis, yet have a straight nonsclerotic lienal artery* (Fig 113) *and, vice versa, an individual may have died from heart disease and still have acquired a markedly tortuous splenic artery* (Fig 114) That tortuosity is not necessarily associated with arteriosclerosis is a justifiable conclusion for tortuosity occurs rather frequently in otherwise normal arteries—external maxillary occipital inferior phrenic external carotid even in the internal carotid which through a protracted loop may *become contiguous to the palatine tonsil* Henschen likewise disparaged the view that tortuosity is correlated with arteriosclerosis In the 72 cases of splenic aneurysms which he investigated the causative factors were manifold (injury infection lues and the like) 12 of the

aneurysms having occurred in individuals of 30 years of age 9 each in individuals 40 and 50 years of age What role increased blood pressure plays in the formation of a tortuous splenic artery remains to be determined It definitely has been ruled out by Karsner as a factor in arteriosclerosis of the larger blood vessels It would appear that only physiology and biophysics can give the answer to the problem of tortuosity The phenomenon merits a major investigation taking into consideration serial microscopic sections of regional arteries age race and normal and abnormal physiologic conditions

The Splenic Arterial Index and Bed Lengths

Since each spleen differs in its type of vascularization the only means whereby variations in the splenic arterial pattern can be judged are the splenic index and the arterial bed length *The splenic index signifies the proportional length of the splenic arterial trunk up to its first branch to the spleen as compared with the total lengths of all lienal branches (including the length of the splenic trunk) The arterial bed length is the total length in centimeters of the splenic artery and all its lienal branches, including the length of the left gastroepiploic involved in furnishing the inferior polar arteries*

Calculations of 50 lienal arterial systems give the following averages splenic index 20 splenic arterial bed length 45 cm number of lienal branches entering the spleen 17 length of the splenic artery up to its terminal division 13 cm Minimal and maximal figures are splenic index 8 to 50 (Figs 130 140) arterial bed length 28 to 92 cm (Figs 138 128) lienal branches 6 to 36 (Figs 146 130) length of splenic artery 8 to 32 cm (Figs 108 128)

Arteries with an index over 25 are *magistral* splenic arteries (30 per cent) with a small arterial bed the total length of which rarely measures more than 35 cm (Figs 112 125 140) The *magistral* splenic artery proceeds to within 2 to 3 cm from the spleen before breaking up into its lienal branches which usually are few and short (Fig 129) The hilus is compact and often does not exceed one third of its medial surface (Fig 140) Polar arteries are absent or very short (Fig 112)

Arteries having a splenic index under 25 are *distributed* splenic arteries (70 per cent) the arterial beds of which are larger at times measuring 80 to 90 cm (Figs 128 130) Their lienal branches are given off early (anywhere from the celiac axis to the spleen Fig 101) They are more numerous and comprise a varying number (1 to 5) of inferior polar arteries and often (65 per cent) a superior polar The hilus of the spleen is distributed at times over the entire gastric surface (Fig 120) The anterior border of the spleen is crenated each notched region as a rule receiving an arterial twig (Fig 126) With few exceptions the following statements hold true *the lower the splenic index (index 8 Fig 130) the more distributed (branched) is the artery the larger is the arterial bed, and the more complicated and the more distributed is the hilus, the higher the index (index 50 Fig 140) the simpler (less branched) is the artery, the smaller is the arterial bed and the more compact is the hilus of the spleen* Exceptions to the rule are instances in which the splenic artery is magistral as far as terminal division is concerned but gives off polar arteries via an early left gastroepiploic (Figs 101 129) In such cases the splenic index without the left gastroepiploic supply would have approximated 50 In spleens having a *double splenic artery or its counterpart—the transverse pancreatic*—two indices may be computed the included extra artery

always lowering the index (17 to 13 in Figure 147 23 to 18 in Figure 121)

Whereas the average splenic arterial index is 20 indices over 30 or under 10 are very rare *The former belong to magistral arteries, the latter to the distributed type* Seriation of 50 splenic indices gave a progressive increase from 8 to 36 with only one index reaching 50 In both the magistral and the distributed arteries the index may be the same or approximately the same as the total arterial bed length (index 30, bed 30 cm Fig 112 index 28, bed 28 cm Fig 138 index 33, bed 33 cm Fig 114) Splenic arteries may have the same total as regards length of arterial bed but show differences in number of lienal branches (30 cm versus 11 branches Fig 123 30 cm versus 21 branches Fig 112 50 cm versus 16 branches Fig 126 50 cm versus 28 branches, Fig 132) Splenic arteries may have the same index (15) but show differences in cm length of the arterial bed and in the number of lienal branches (33 cm 14 branches Fig 107 92 cm, 33 branches Fig 128)

Remarkable variations in the vascularization and the morphology of the spleen were met with—to wit, an arterial bed of 30 cm (Fig 116) *as compared with one of 60 or 90 cm* (Figs 106 105) *7 lienal branches* (Fig 118) *as compared with 14, 21, 28 or 35* (Figs 107 112 132 130) *a splenic artery 8 cm long* (Fig 108) *as compared with one 16, 24 or 32 cm long* (Figs 104, 137 128) *an artery 5 mm in width* (Fig 150) *as compared with one 10 mm in width* (Fig 106) *a spleen 2 to 10 times larger than that of another* (Figs 105 136) *splenic arteries that are straight (15 per cent) and short (8 to 10 cm* Figs 108 112) *as compared with those that are long (15 20 or 32 cm) and tortuous (moderately curved 45 per cent markedly looped, twisted and coiled 40 per cent* Figs 103 105 128)

As outlined above the lienal divisional patterns of the splenic artery are intimately correlated and co extensive with the morphologic variations of the spleen, especially of its medial surface, where the vertical lines of vessel entrance vary from 4 to 12 cm the frontal planes of vessel entrance from 3 to 15 cm The magistral and the distributed lienal arteries pertain respectively to the different types of spleens (1) compact type with even borders and narrow hilus (2) distributed type with distributed hilus crenated anterior and posterior borders thumblike lobe at inferior pole a tubercle at the superior pole and numerous pits for the entrance of arterial twigs some pits being located even on the renal surface

It is highly probable that these marked constitutional variations in the blood supply and the morphology of the spleen are related to differences in the normal and the abnormal physiology of the individual but what these are has as yet not been determined *The ever varied blood supply and the morphology of the spleen strikingly illustrate the basic principle of constitutional variation, dormancy of which has too long been sustained by textbook illustrations and didactic teaching Morphologic variation may be a basic factor in physiologic behavior and pathologic disturbances a field as yet uncovered and open for pioneer investigation, primary organs to begin with being the pancreas and then the adrenal gland*

The Intrasplenic Circulation

Splenic Arterial Anastomosis

The problem of an extensive intraorganic collateral circulation in the spleen is largely as unsolved as it was in the days of *Mall (1900)* For orientation purposes the following short summary of the internal structure of the spleen will help elucidate the points discussed *Grossly considered the splenic tissue*

consists of red and white pulp which fills the spaces between the trabeculae Like the capsule the latter is made up of dense connective tissue and contains collagenous and elastic fibers and smooth muscle cells The white pulp consists of ordinary lymphoid tissue distributed as a sheath along the course of the arteries up to a point where the latter attain a diameter of 15μ In a freshly cut surface it has the appearance of long curved branched round gray areas The red pulp is a special modification of the white pulp that lies between the venous sinuses As the intersinusoidal reticulum (Billroth s cords) with free cells in its meshes it constitutes the largest part (80 to 85 per cent) of the splenic weight (Hellmann 1926) At the periphery of the malpighian corpuscles (spheroid or egg shaped follicles within the lymphoid sheath along the arteries) the white pulp merges with the red pulp the reticular network of one being continuous with that of the other Adjacent to the limiting reticular membrane of the malpighian corpuscles there is a zone of reticulum which contains some erythrocytes but is devoid of sinuses

The relative amounts of red and white pulp vary in a marked degree in different animals and also in man at different ages and during the course of different diseases The number and the types of free cells (lymphocytes monocytes histiocytes erythrocytophages granulocytes) vary not only in different individuals but also in different areas of the same spleen The same is true of the red blood cells the greatest number being around the follicles

Structures of the splenic venous routes inside the spleen comprise the venous sinuses the capillary veins the pulp veins and the trabecular veins In contrast with the trabecular arteries which have definite muscular walls the walls of the trabecular veins are composed only of endothelium and the supporting connective tissue of the trabecula up to the hilus as may be seen in any histologic section In consequence of this the trabecular veins most probably use the structural elements of the trabeculae when functioning—i e what the trabecula does that likewise is the fate of the vein In view of this fact it is not unlikely that when some of the trabecular veins contract they open up thus allowing a freer return into the splenic veins The control of the lumen of the artery is independent of the surrounding trabecula for the arterial wall is well developed as regards both the internal elastic membrane and the adventitia (see Klemperer s Figure 8) According to Kultschitzky (1895) the arrangement of its vascular wall and its definite demarcation from the surrounding trabecula permit a certain degree of mobility of the artery in a longitudinal direction

The entering splenic arteries along with the veins are at first enclosed in a thick fibrous trabecular sheath derived from the capsule After a varied short course the artery becomes separated from its accompanying vein but retains its trabecular sheath (trabecular artery) When the latter has reached a diameter of 0 2 mm it leaves the trabeculae loses its fibrous sheath and becomes surrounded with a sheath of lymphoid tissue which collectively considered constitutes the white pulp Along the course of the branching artery the lymphoid sheath forms the malpighian corpuscles In these the artery is known as the central or follicular artery It is frequently eccentric in position and when the malpighian corpuscle is formed at branching point of the artery it is double The terminal branches (3 to 4) of the follicular artery lose their lymphoid tissue and enter the red pulp as a brush of precapillary *arterioles* commonly known as the penicilli or

pulp arteries (penicilli of Ruysch, 1721) pulp arteries (Weidenreich 1901) sheathed arteries (Jäger, 1928), pulp arterioles (Riedel 1932) Ramifications of the pulp arteries comprise the arteriolar, the sheathed and the terminal capillaries When the terminal arteries have reached a dimension of 5μ they lose their muscular coat and become surrounded with an ellipsoid sheath known as the Schweigger Seidel (1862) capillary sheath ellipsoid or filtration apparatus After leaving the latter the terminal capillaries end freely in the meshes of the reticulum of the red pulp (advocates of the open circulation) or communicate directly with the venous sinuses (advocates of the closed circulation)

Intrasplenic Anastomoses In a study of 100 spleens the author noted that the number of lienal branches entering the spleen varied from 7 to 35 These entering arteries become subdivided in different individuals in an extremely variable and seemingly undeterminable number of arteries Kyber (1870) divided the spleen into as many lobes as there are arteries and each lobe into as many *lobules as there are arterial subsidiary* branches Mall (1900) regarded the anatomic unit as a mass of pulp about 1 mm in diameter with the main veins and muscles (trabeculae) on its periphery and the artery in its center He estimated that in the dog there were about 80 000 of these units each lobule being subdivided into about 10 histologic units by intralobular trabeculae Gremsius (eighteenth century) counted 4 000 splenic arteries Mall calculated 400 million arterial endings Henschen by radiographic injections distinguished 4 to 10 main arterial zones The arteries are usually regarded as end arteries (Cohnheim 1872 Tait and Cashin 1925 Klemperer 1938 MacKenzie et al 1941) because they do not anastomose with one another, except at the hilus periphery where inside the spleen there is a well defined zone of intraorganic transversal communications (Volkmann 1923, Henschen 1928)

In a study of living mammalian *spleens transilluminated with the fused* quartz rod technic MacKenzie Whipple and Wintersteiner of Columbia University (1941), noted that arterial anastomoses were wholly intralobular and that if one of the main pedicle branches of *the splenic artery was ligated an infarct* of the homologous portion of the spleen became so sharply demarcated that rather less than 0 2 mm may be seen to separate the zone of complete stasis from that of normally circulating blood In view of this they regard the splenic arteries as end arteries (i e, they do not anastomose proximally to their respective intralobular ramifications)

At the periphery of the splenic follicle the primary divisions of the follicular arteries were seen to divide into 2 to 3 small branches which very definitely penetrated the marginal zone of the red pulp constituting the penicilli of Ruysch (1721) After leaving the follicle in *radial or tangential fashion the penicilli* (maximal diameter 8μ to 10μ) followed a straight or curved course through the pulp but rarely anastomosed no interpenicillar anastomoses having been observed in the cat

Extrasplenic Anastomoses In the spleens studied these comprise a widespread system (30 per cent) of outer hilar transverse communications between branches of the splenic artery As shown in the author's illustrations such anastomoses occur commonly between the superior and the inferior terminals (Figs 105 118 131) between the superior polar artery and the superior terminal (Figs 131 132) between the inferior polar and the inferior terminal (Figs 136 149), between the splenic

trunk and the superior polar (Fig 116) all allowing collateral circulation

THE INTERMEDIARY OR SEPARATORY CIRCULATION OF THE SPLEEN

The mode of intrasplenic circulation is complicated by the still much disputed character of the intermediary vascular patterns between the arteries and the venous sinuses and venules We know the character of the arterial capillaries reaching into the pulp cords up to the point where they lose their endothelium We know the structure of the venous sinuses (Peck and Hoerr) for they are composed of indented longitudinally arranged endothelial cells (endothelial ridges Hartmann 1930 Stabzellen Weidenreich 1901) which are separated by narrow splits (mural stomata) and are surrounded by annular reticular fibers disposed about the sinus like the hoops of a barrel but what of the vascular channels that actually connect the arteries and the venous sinuses and veins? Are the arteriovenous anastomoses but dilated pulp spaces between the terminations of the capillary ampullae and the venous sinuses as claimed by Mall (1900) or do such connections really exist?

Despite the vast amount of investigative work that has been done during the last 100 years on the subject of splenic arteriovenous connections and the different technics used to solve the problem no unanimity of opinion exists today whether the circulation of the spleen is an open or a closed one as recently emphasized by both Bjorkman (1947) and Herrlinger (1949) An excellent review of the literature on the intermediary circulation of the spleen as seen in fixed and stained tissues is given by Klemperer in Downey s *Handbook of Hematology* (1938) A method of studying it in living tissues by a fused quartz rod technic is given by Knisely of the University of South Carolina in Mc Clung s *Handbook of Microscopic Technique* (1937)

Methods of studying the splenic circulation comprised injections of fluids soluble and nonsoluble dyes (Thoma 1895 Mall 1900) or particulate matter (Mall 1900) of yeast cells (McNee 1931) and defibrinated blood (Kelly 1903) x ray film studies after injections of radiopaque substances (Henschen) specific staining (Hoyer 1900 Weidenreich 1901 Mollier 1911 Foot 1927) reconstruction models (Hoffman and Bennett 1927 Hellsten 1928 Jager 1939 Koboth 1939 Snook 1944 1950 Martin 1951) fixation of splenic tissue at maximal distention through injection of Formalin (Doggett 1951) and finally study of living transilluminated spleens by the fused quartz rod technic (Knisely 1936 MacKenzie Whipple and Wintersteiner 1941 Peck and Hoerr 1951 Palm 1951 Nakata 1954)

The commonly accepted theory of an open circulation implies that the whole blood floods the pulp spaces (interstices) after leaving the abruptly ending arterial capillary ampullae In other words instead of coursing through preformed endothelium lined vessels the blood flows freely through the reticular meshes of the red pulp Fusion of contiguous pulp spaces the funnel shaped enlargement of one or more of them gives rise to the venous sinuses (capillary vein of Billroth 1857 primordial vein of Robin 1890) whereby the blood reaches the vein through holes or stigmata in their walls That the sinus wall is not closed but perforated and consists of a netlike reticular syncytium identical with the general fibrillar reticulum of the pulp was first demonstrated by Mollier (1911) in his classical studies on reticulum Mollier s concepts have been confirmed substantially by numerous investigators (Thiel and Downey 1921 Neubert

1922 Robinson 1926 Foot, 1927 Mac Neal Otani and Patterson 1927 Hueck, 1928 Klemperer 1938)

According to MacKenzie et al (1941) *the functional* control of the splenic circulation is regulated by the contraction of the capsule and the trabeculae Ellipsoids (capillary sheath) take part in the process but the venous sinuses have *nothing to do with it*

Klemperer of Mt Sinai Hospital New York (1938) explained the open circulation as follows

Because of the netlike structure of the arterial *terminations as well as of the* venous sinuses the circulation is evidently open However the width of the stomata is *variable and is influenced by various* factors For instance contraction of the spleen will cause a diminution of the size of the pores whereas increased tension within the vascular channels provoked by elevation of the arterial or venous pressure will result in a dilatation of the stomata within the vascular wall Furthermore changes in the colloidal phase of the cytoplasmic reticulum with concomitant swelling or shrinkage of the trabeculae of the grid must necessarily cause either a decrease or an increase in the width of the stomata It is evident that if the pores in the vascular channels are wide open blood will escape freely into the surrounding pulp spaces whereas if they are narrow the blood will remain within a pathway separated from the surrounding spongy spaces of the pulp by a perforated but very narrow meshed wall This concept (Hueck 1928) reconciles the opposing view points regarding the existence of an open or closed blood circulation in the spleen It is structurally open but functionally may be closed or open or as expressed by Hueck orderly or disorderly (Downey s *Handbook of Hematology* vol 3 p 1632 New York Hoeber 1938)

Advocates of the theory of a closed circulation in its modern modified form maintain that the blood passes through structurally intact interconnected definitely lined arteriovenous channels the functional control of which is regulated by sensitive sphincters located at the afferent and the *efferent ends of the* venous sinuses, or arteries on ellipsoids (Schweigger Seidel rings) and *on capillaries* at the point where each capillary enters the sinus (Knisely 1936 Peck and Hoerr 1951) Although Knisely admits that From the visibile structure alone one might easily conclude that *the splenic vascular system is* 'closed he objects to the terms open and closed as both are inadequate to cover splenic circulation Because the sinuses separate blood cells quantitatively from the blood fluid the circulation is not closed and because the whole blood is not poured freely into the intercellular spaces of the pulp partitions, the circulation is not open When occasionally red cells leave the vascular system they do so by diapedesis or penetration the red cell being distorted in the passage through the sinus wall

In his first work on splenic circulation conducted at the Hull Laboratory of Anatomy University of Chicago Knisely (1926) made a report on his studies on the anatomic relations of the vascular system and the routine activities of the circulatory system in living *unstimulated spleens* of 75 white mice 30 white rats and 15 cats His second paper deals with his observations on traumatized and dying *spleens* After exposing the spleen through a hole in the body wall the posterior ventral end of it was transilluminated by means of a fused quartz rod and studied care being taken not to disturb either the spleen or the animal

In view of their importance and to *avoid misinterpretation* Knisely s observations will be presented here for the most part in his own words As to anatomic structures *Knisely noted that*

The structures of the living splenic vascular system stand out like the injected vascular systems of whole mount preparations of other organs So as in studying a

whole mount one has to focus up and down and move along the vessels to trace out their connections

The venous sinuses are seen to be definite anatomical units shaped roughly like sweet potatoes or like cucumbers They pene trate the tissue in all directions each like a short narrow-ended tunnel drilled in a cheese The shape and size of a sinus varies depending upon which phase of its physiological activity it is in Venous sinuses are specific anatomical units and are not to be confused either structurally or functionally with capillaries venules or arterio-venous anastomoses

The tissue between the sinuses consists of thick or thin partitions the thickness of a given partition at a given time depends upon how much it is squeezed between and stretched by the adjacent venous sinuses The increase in the size of the sinuses during some phases of their activity concomitantly decreases the thickness of the partitions and vice versa In cutting sec tions of the spleen this set of irregular par titions is cut in various directions thus creating by act of cutting the appearance of irregular rods and bars known as Bill roth cords The splenic pulp of mice rats and cats does not consist of a three-dimen sional network of cords suspended in blood

There are relatively few red cells in the pulp partitions (that is Billroth cords) of the living unstimulated spleen When a red cell passes through the lining of the vascular system its shape is distorted in a characteristic manner as it begins to penetrate the lining and the red cell snaps forward suddenly as soon as the major part of its protoplasm has passed through the lining membrane (This snap ping forward is like the snapping forward of a moist apple seed when pinched be tween one s thumb and forefinger) The initial distortion of the red cell I take to be evidence that the lining membrane offers resistance to the penetration of the eryth rocytes and the snapping forward to be evidence that the lining membrane is elastic and exerts pressure on the erythro cyte which is traversing it

The lining of arterioles arterial capil laries capillaries venous sinuses and ven ules appears in the living spleen as a narrow clear sharply refractile line the refrac tile linings of the vascular system of the living unstimulated spleen are as continuous as but thinner than the refractile linings of arterioles and venules in most other tissues such as smooth muscle for instance Each vessel traced was attached to other vessels at each of its ends (*Anat Rec* 64 199 1936)

As regards the artery of the mal pighian corpuscle Knisely noted that it divides in 3 to 4 (occasionally 7) main branches each of which subdivides into 2 to 4 smaller branches these being the penicilli Each of the latter gives off 2 to 4 short branches the subdivisions of which constitute the arterial capillaries Anastomoses between branches of a single penicillus and branches of adja cent penicilli were observed The capil laries of the malpighian corpuscles form a three dimensional network the pattern of which is essentially the same as that obtaining in other tissue Peripherally the capillaries join the capillary network which connects the branches of the penicilli

Control of the circulation is accom plished by powerful sensitive sphincters located at strategic points such as (1) ellipsoids (2) on each arterial capillary above the point where it enters the sinus (3) at the efferent end of the sinus The sphincters have a valvelike action and may change from a fully open to a closed condition in a very short time

To resume Knisely s description

There are two anatomically different types of preformed lined vessel systems in the red pulp which connects arterioles or arterial capillaries to venules One type consists of venous sinuses and venous sinus systems The other consists of long straight or somewhat curved capillaries No anas tomoses between these two types have yet been found

Many of the arterial capillaries after a short course connect directly with the af ferent ends of venous sinuses A smaller

number enter laterally There are sinuses which have no other type of afferents and connect directly with a venule This type of connection constitutes a single sinus route There are also multiple sinus routes Thus the efferent end of a venous sinus may be connected to the end or side of a second sinus The multiple sinus routes have two or three or more consecutive venous sinuses interposed between arterial capillary and venule There is a functional as well as a structural difference which distinguishes single from multiple sinus routes

Each single and each multiple sinus route is a definite anatomical unit The anatomical connections of a given route have remained constant throughout all observed physiological cycles of that route

For consideration of fluid flow it is important to note that though some sinuses have side afferents and some do not each sinus has an end efferent

Many arterial capillaries derived from the subdivisions of the penicilli pursue a long somewhat curved unbranched course They pass lengthwise through the pulp partition tissue between the sinuses and connect directly with venules Many authors have described the first portion of these capillaries but as far as I know their ultimate termination has not been previously described For consideration of function it is to be noted that these long capillaries are connected in shunt with the sinus system

The afferent connections of the smallest venules are of three kinds (1) Efferent ends of single sinus routes (2) efferent ends of multiple sinus routes (3) efferent ends of the long relatively straight capillaries The smallest venules join together to make larger venules the structure and connections of which are well known

Each vessel traced in the living spleen was connected to the arterial system and to the venous system No vessels have been seen to open out into or pour blood into intercellular pulp spaces in living unstimulated spleens No vessels have been seen to end in culs de sac In the living unstimulated spleen the vascular system consists of a series of completely interconnected preformed lined channels (*Anat Rec* 65 23 1936)

The activities of the venous sinuses and multiple sinus route systems according to Knisely are of two types cycle and continuous both types separate the cells of the blood from the fluid The primary purpose of the venous sinuses then is not to conduct blood but to separate blood cells quantitatively from the blood fluid This may be effected in two ways (1) by the filtering filling process (2) by the conduction filtration process The former represents cyclic activity of the venous sinuses and comprises the following phases (1) filtration filling during which the venous sinus swells to several times its previous volume (2) a storage phase (3) a phase of sudden emptying (4) a conduction phase during which the whole blood flows into through and out of the sinus Knisely concludes his report with the statement

Precise integrated control of the distribution of blood is one of the dominating features of the activity of the splenic vascular system The proportion of blood which passes through the spleen without having its cells separated from its fluid the proportion having its cells separated from its fluid and the length of time the cells are stored are continuously controlled This control is secured by the coordinated action of sets of sensitive powerful reactive sphincters located at strategic positions The sheaths of Schweigger-Seidel act as especially powerful sphincters

The venous sinus and venous sinus systems are not primarily a system of vessels which conduct blood to nourish the splenic tissue The sinus systems and pulp partitions constitute rather a mechanism which acts upon blood (*Anat Rec* 65 23 1936)

In his report on observations on traumatized and dying spleens Knisely (1926) states that two reactions are initiated by manipulative stimuli (1) complete simultaneous contraction of

sphincters especially of ellipsoids (2) passage of many erythrocytes from sinuses in the storage phase into the pulp partitions These reactions (a) explain the difficulty of injecting the splenic pulp by way of the arteries (b) account for the fact that material injected into the veins does not come out of the arteries (c) explain the presence of holes in the walls of fine vessels of injected specimens and (d) explain the presence of a portion of the erythrocytes seen in the pulp cords of sections of spleen

Agonal changes varied in degree and occurred very rapidly at times beginning in 5 minutes and ending in 10 minutes Sudden agonal changes may account for much of the contradictory statements found in the literature regarding the histology of the splenic vascular system The agonal changes may have taken place before the tissue was fixed The agonal changes produced were (1) migration of erythrocytes into the pulp (2) disappearance of portions of the arterial-capillary and capillary walls (3) appearance of irregularly shaped moving cells which rapidly ingested and cytolized erythrocytes (4) development of spaces in the sinus wall sufficiently large not to distort red cells passing through them (5) relaxation of distended and stretched pulp partitions which alter the tissue the relative magnitude of its parts no longer being the same

Subsequent Denial and Confirmation of Knisely s Work

To the surprise of many who believed that the problem of splenic circulation had at last been solved by the findings and the contentions of Knisely these were categorically denied by MacKenzie Whipple and Wintersteiner (1941) Using the same technic of studying the splenic circulation in living transilluminated spleens that he had learned in Knisely s laboratory in Chicago MacKenzie in a restudy of Knisely s findings at Columbia University at a later date came to directly opposite conclusions to wit that there were no preformed structurally intact interconnected vascular channels between the arteries and the venous system In the large series of animals investigated (210 mice 13 cats 12 rats 8 guinea pigs 6 rabbits) the circulation was always *open,* the arterial capillaries invariably terminating in the red pulp Furthermore there was no evidence of the *cyclic activity* (filtering filling storage emptying and conduction phases) of the venous sinuses Any of the cited phases could be studied in a relaxed spleen but they occurred not in the sinuses but in the intercellular channels of the pulp the periodicity of the component phases being totally irregular The venous sinuses show innumerable stigmata which permit the outflow of red and white cells from the pulp The sinuses have nothing to do with the control of the circulation They do not act as storage reservoirs nor do they exhibit cyclic activity While vascular activity in the pulp may be rhythmic or intermittent the only true rhythmic changes which occur are those caused directly by the contraction of the spleen as a whole

With the work of MacKenzie et al the solution of the intermediate splenic circulation as ascertained by Knisely with the transillumination method seemed definitely refuted and disparaged Peck and Hoerr (1951) however in a reduplication of some of the investigative work of MacKenzie gave substantial evidence that the concept of Knisely is probably the correct one Hoerr was a colleague of Knisely while at Chicago and was one of the first to confirm the storage phase of the venous system With an experience of 15 years in the technic of studying transilluminated living spleens by the quartz rod method on the part of Hoerr and 5

years on the part of Peck these authors were able *to confirm in a large series of* mice (350) both the morphologic and the physiologic aspects of the intermediary *splenic circulation as ascertained by* Knisely to wit existence of preformed interconnected intactly lined channels connecting the venous *and the arterial* systems single and multiple cucumber like dilatations of the venous sinus continuity of the smooth lining of the sinuses with the refractile wall of the afferent capillary existence of long slender capillaries which bypass the sinuses and as shunts conduct blood directly from arterioles to venules when blood cells are being stored in the sinuses They likewise confirmed all phases of cyclic activity of the venous sinuses as described by Knisely (filtration filling storage emptying and conduction phases) along with the sphincteric activity of the sinuses of the arteries that of the penicillar arteries being the most powerful seen in splenic circulation Contraction of the spleen was seen in nearly every mouse studied but these were grossly undectable ir regular irrhythmic and did not materially affect the circulation To cite Peck and Hoerr of Western Reserve University in their own words

> All of the phases of activity of the sinuses described by Knisely have been observed The efferent end of a sinus may constrict *so that no blood passes into the efferent* venule Blood continues to flow into the sinus which increases in diameter At the efferent end of the sinus the cells are packed more closely together until they form a dense red homogeneous mass and the individual cell outlines may no longer *be seen* When a sinus contains only packed red cells the flow may stop for varying lengths of time from a few minutes up to several hours White cells can be seen easily in the densely packed red mass
>
> The emptying of a sinus may occur suddenly and completely slowly or by spurts The stored cells enter the venule in small densely packed clumps which suddenly *break apart to individual cells* The diameter of the sinus again decreases to about 10μ and conducts blood rapidly so that it is impossible at times to distinguish it from a capillary until it fills and dilates again
>
> The continuous filtering phase of the sinuses described by Knisely has also been observed In this phase the sinus conducts blood continuously but as the blood cells pass through the sinus they come closer *together This approximation of the cells* appears to be due to loss of plasma since there may be no change in the diameter of the sinus nor any evidence of a peripheral plasma layer During this phase of activity the sinus may for long periods have approximately twice the diameter of a capillary (15μ to 20μ)
>
> The storage phase of the sinus usually has the longest duration the filling and emptying phases progressing rapidly as a rule The conduction phase and the continuous filtration activities are predominant in the contracted spleen the storage phase is more frequent in the dilated spleen (*Anat Rec* 109 479 1951)

Peck and Hoerr give two reasons why MacKenzie Whipple and Wintersteiner failed to confirm the findings of Knisely and came to such contradictory results They are (1) they *did not prevent* minute vibrations these being the greatest hindrance to good microscopic definition *at high magnification* As a fisherman can no longer see anything below the surface of the water when it rains so infinitesimal vibrations transmitted through the building and supporting table in transillumination studies can so distort clear vision that a penicillar artery ending in branches which abruptly turn out of the plane of focus might well appear to open into pulp spaces (2) MacKenzie *et al* were dealing with overheated spleens When mouse spleens were exteriorized and suspended in a tray exactly as described by MacKenzie the circulation in the red pulp became constant and rapid as a result of which the storage

phases of the venous sinuses and their sphincteric activity were abolished while the sphincteric action of the arteries and the arterioles was retained When the temperature of the Ringer solution bathing the spleen was raised to 40 5° C they obtained a pattern of splenic circulation comparable with that of MacKenzie while when the environmental temperature was lowered below 37 5° C the red blood cell storage activity of the sinus was increased A sudden raising or lowering of the spleen s temperature caused an immediate pronounced contraction of the spleen At a high temperature the initial contraction was followed by a dilatation during which the venous sinuses emptied completely and conducted blood at a rapid rate At a lower temperature the contraction was likewise followed by a dilatation but the venous sinuses were predominantly in the storage phases

Peck and Hoerr with the approval of Knisely suggest that the special intermediary type of circulation between the arteries and the venous sinuses in the spleen might be termed separatory circulation in view of its peculiarity of leaking blood plasma particulate matter and even some blood cells to the extravascular spaces of the red pulp

Anatomically considered for many years the view has prevailed that typical capillaries either arterial or venous are lacking in the spleen The view is based on the experience of most investigators in that they could not trace the continuity of capillaries in the spleen in histologic sections (Mall MacNeal) Arterial capillaries opening into the sinuses have been observed by many investigators (Weidenreich 1901 Bjorkman 1947 Herrlinger 1949) Snook (1944 1950) saw them in graphic reconstruction models and their occurrence in living tissue definitely has been established by Knisely Peck and Hoerr

Doggett (1951) claims that failure to find venous capillaries is due to the fact that when the spleen contracts and is then fixed as happens in ordinary procedures the venous capillaries are collapsed and hidden in the compressed reticulum and arterioles appear as free vascular channels If however, the spleen is injected to the limits of its capacity with Formalin or other fixative the capillaries will be distended and accordingly will be readily visible within the dispersed pulp The venous capillaries that come to view are true connecting links between arterial capillaries and sinuses Nakata of the Osaka Medical School Japan (1954) devised a new apparatus for studying transilluminated spleens in living mice and made a motion picture film of his findings While his observations are in substantial agreement with those of Knisely Peck and Hoerr he did not see red cells penetrate the walls of venous sinuses nor did he observe free erythrocytes in splenic cords

Summary of the Blood Supply of the Spleen

The arterial blood supply of the spleen is so varied that no two vascularization patterns are ever the same (100 dissections) The length of the splenic artery varies from 8 to 32 cm (average 13 cm) and the width varies from 5 to 11 mm (average 7 5 mm) The number of arteries entering the spleen varies from 6 to 36 an average being 17 A small spleen may have a larger number of entering arteries than a large spleen and vice versa The differences in the vascularization patterns are intimately correlated and coextensive with differences in the morphologic contours of the spleen which are never the same

Typically the first segment of the splenic artery is suprapancreatic the second pancreatic the third prepancreatic the fourth (the prehilar segment) lies between the tail of the pancreas and

the spleen Often the artery runs an atypical course and may then be retro pancreatic prepancreatic intrapancreatic totally or only in part

As a rule the splenic divides 2 to 6 cm from the hilus into a larger arteria terminalis superior and into a smaller arteria terminalis inferior A third terminal branch is often formed the arteria terminalis media The terminal branches give off ultimate and penultimate branches which may be short or long (1 to 10 mm) few or numerous (2 to 12) of small or large caliber (0 5 to 3 mm) The splenic the terminals and their branches give off a varying number (2 to 10) of short gastrics and omental branches

Peculiarities of the lienal branches are their prevailing rectangular dichotomic origin their manifold variations in caliber length and distribution and their frequent outer hilus transverse anastomosis with each other

The upper pole of the spleen is often (65 per cent) supplied by the a polaris superior (2 to 12 cm) It usually arises from the splenic trunk or its superior terminal branch rarely from the inferior terminal It may come from the celiac thereby providing the spleen with a double splenic artery (2 cases) It is frequently long (9 to 12 mm) slender (1 mm) and tortuous and because of these facts may readily be missed in splenectomies Short gastrics arise from both before and after its lienal branching

The inferior extremity of the spleen in the majority of instances (80 per cent) has two to three inferior polar arteries They usually arise from the left gastro epiploic but may come from *the a terminalis inferior or its branches* They are selectively distributed to notched areas and often carry the blood supply to the accessory spleen located in the lienogastric or the lienophrenic ligament

In site of origin number of lienal branches (1 to 1) and modes of arterial *connections with the spleen the left* gastro epiploic is extremely variable Typically it arises from the splenic previous to its primary terminal division next in frequency from the a terminalis inferior or its branches least frequently from the a terminalis superior The artery may be represented by 2 to 4 smaller vessels Collectively considered *the blood supply coming from the left* gastro epiploic through its splenic branches may approximate that reaching the spleen through its primary lienal branches Branches of the left gastro epiploic are the lienal inferior polars the short gastrics the left epiploic the omental and the pancreatic branches The left epiploic constantly forms the left limb of the arcus epiploicus magnus of Barkow found prevailingly in the posterior layer of the great omentum below the transverse colon which it supplies with ascending rami the posterior epiploics

The divisional patterns of the splenic artery are intimately correlated and coextensive with the morphologic variations of the spleen especially of its medial surface where vertical lines of vessel entrance vary from 4 to 12 cm and frontal planes of vessel entrance vary from 3 to 15 cm The spleens showed the following shapes orange segmentlike 44 per cent tetrahedral 42 per cent triangular 14 per cent Two types of spleen can be distinguished (1) a compact type with even borders and narrow hilus (2) a distributed type with distributed hilus notches (2 to 6) at anterior and posterior borders thumblike lobe at the inferior *pole a tubercle at the superior pole* numerous pits for vessel entrance some of them being located even on the renal surface

The two types of spleen give rise to two types of splenic arteries a erminal

lienal branching (1) the magistral type (30 per cent) in which the splenic trunk is long terminal division occurs near the hilus branches are few, large and enter one third to one fourth of the medial surface The superior polar artery is usually absent when present it is usually short (2) The distributed type (70 per cent) in which the splenic trunk is short lienal branching occurs early anywhere from the celiac to the hilus branches are more numerous and smaller in caliber include superior and inferior polars and enter three fourths of the medial surface at times being distributed to the entire gastric surface in successively placed frontal planes Between the magistral and the distributed splenic arteries there are many intermediate types due to the fact that an early left gastro epiploic with inferior polars may change an otherwise magistral vascularization into a distributed type

The only means whereby variations in the splenic arterial patterns may be judged are the splenic index and the magnitude of the lienal arterial bed The splenic index is the ratio of the length of the splenic trunk up to its first branch to the spleen as compared with the total length of all lienal branches including the length of the splenic artery The magnitude of the arterial bed is the total length in centimeters of the splenic and its lienal branches Splenic arteries with an index of over 25 are magistral those below 25 are distributed With few exceptions the rule holds that the lower the splenic index the more distributed (branched) is the splenic artery The indices varied from 8 to 50 an average being 20 The total lengths of the arterial bed varied from 28 to 92 cm an average being 45 cm

Remarkable constitutional variations were met an arterial bed of 30 cm as compared with one of 60 or 90 cm 7 lienal branches as compared with 14 21 28 or 35 a splenic artery 8 cm long as compared with one 16 24 or 32 cm long an artery 5 mm in width as compared with one 10 mm in width a spleen 2 to 10 times larger than that of another splenic arteries which are straight (15 per cent) and short (8 to 10 cm) as compared with those which are long (15 20 or 32 cm) and tortuous (moderately curved 45 per cent markedly looped twisted and coiled 40 per cent)

The most pronounced characteristic of the splenic artery is its tortuosity which manifests itself in curves loops and spirals primarily in the splenic trunk secondarily in its terminal and ultimate branches The phenomenon is correlated with the lengthening (from 10 to 32 cm) and thickening (from 7 to 11 mm) of the artery and with age it being progressively more marked and of greater frequency in individuals over 50 years of age Whatever its significance and its genesis it is an ideal mechanism to slow up the blood flow to the spleen both volumetrically and in point of force thereby protecting the soft pulp portion of the spleen

In studying the spleen and its hilus the surgeon may surmise its type of vascularization in the sense that a notched spleen with an uneven anterior border a prominent tubercle and a wide and distributing hilus will as a rule present a distributed or early and complicated type of vascularization with prevalence of polar arteries whereas a spleen with an even anterior border and a narrow and compact hilus will have a magistral or late relatively simple type of lienal branching without polar arteries

Diversity of splenic vascularization is correlated with developmental differences of the original multiple splenic hillocks in the dorsal mesogastrium The selective distribution of arterial twigs *to* notched areas to tubercles and to accessory spleens attached or detached (seen also in infants) supports this view

Armed with experiment and
Calculation science seeks truth
Canones universales regulae

—ROGER BACON Opus Majus (1276)

9

Blood Supply of the Pancreas and the Duodenum

The Peripancreatic Arterial Circle

Pistol like in shape and with a length of 16 to 20 cm and a width of 4 to 5 cm the pancreas lies in three peripancreatic interlocking arterial circles made respectively by the hepatic the splenic and the superior mesenteric arteries These three large arteries along with the celiac trunk furnish the arterial blood vessels to the pancreas and the organs immediately associated with it viz the duodenal loop the proximal portion of the jejunum the pyloric end of the stomach and the first part of the duodenum and the spleen

In view of the fact that the blood supply of the liver conforms to the standard textbook description in only about one half of the population it is not surprising that the pancreas should likewise show decided variations in the patterns of its arterial vascularization In finer details these patterns vary practically in each instance thus conforming to the conditions existent in the vascularization of the spleen and the liver The following pattern may be regarded as typical

The head of the pancreas and the horseshoe shaped loop of the duodenum associated with it are supplied by branches from two pancreaticoduodenal arcades one being anterior the other posterior to the head of the pancreas

The anterior pancreaticoduodenal arcade is formed by the (anterior) superior pancreaticoduodenal, the smaller of the two end branches of the gastroduodenal The posterior pancreaticoduodenal arcade is formed by the retroduodenal artery (sometimes called the posterior superior pancreaticoduodenal) a collateral and usually the first branch of the gastroduodenal before or immediately after it passes behind the duodenum The two arcades unite with the superior mesenteric via a separate inferior pancreaticoduodenal given off by the superior mesenteric for each arcade or both arcades end in a common inferior pancreaticoduodenal (Figs 50 49) Incidence of the latter is 60 per cent its point of origin most commonly being the superior mesenteric the first or second jejunal branch (Figs 72 90) often it arises from an aberrant right hepatic (Figs 84 88)

The anterior arcade is described and illustrated in texts of anatomy and surgery the posterior usually is not It is in virtue of these two pancreaticoduodenal arcades that the duodenum is the only section of the gut that has a *double blood supply* one to its anterior, the other to its posterior surface

As depicted in the author's illustrations the anterior and the posterior arcades show many structural [illegible]ons

They may be single double triple and even quadruple entirely or only in part As with other vascular arrangements patterns commonly met with may be categorized into types Of these the following are most instructive

Types of Anterior Pancreaticoduodenal Arcades

Type I Single Anterior Arcade The anterior arcade is only partly visible from the front as its distal portion is located in the substance of the pancreas It begins with the superior pancreaticoduodenal artery which varies in caliber and is often tortuous in its initial course After making a loop of a half circle or less on the anterior surface of the pancreas (medial to the groove between the pancreas and the duodenum) the superior pancreaticoduodenal sinks into the pancreas turns to the left ascends and upon reaching the posterior surface of the head of the pancreas joins the inferior pancreaticoduodenal descending from the superior mesenteric (Fig 50) The loop gives off 8 to 10 relatively long branches to the anterior surface of all three portions of the duodenum and from 1 to 3 branches to the first part of the jejunum It supplies numerous branches to the pancreas some of which are arranged in arcade fashion and anastomose with branches given off by the uncinate branch of the dorsal pancreatic this branch being a separate and an important route of blood supply from the celiac region to the pancreas The uncinate branch most commonly passes behind the portal vein (Fig 66)

The inferior pancreaticoduodenal which constitutes the distal end of the arcade is markedly varied in length and in point of origin Commonly 2 to 5 cm long it may be only a short stub of less than 1 cm Its point of origin from the superior mesenteric may be high low or intermediate When two inferior pancreaticoduodenals are present the one for the inferior arcade is usually lower (Fig 50) It may arise to the right, to the left or from the front of the superior mesenteric Quite frequently it takes origin from the first or the second jejunal branch to the right or the left of the superior mesenteric (Figs 70–73) The superior pancreaticoduodenal may join an inferior pancreaticoduodenal which has no connection at all with the superior mesenteric but takes origin from an aberrant right hepatic derived from the superior mesenteric in which case it takes a long course through the pancreas and behind it (Fig 88) A portion of the intrapancreatic part of the anterior arcade may anastomose with an inferior pancreaticoduodenal arising from the superior mesenteric or from its first jejunal branch another portion may join an inferior pancreaticoduodenal given off by an aberrant right hepatic derived from the superior mesenteric and which passes behind the head of the pancreas (Fig 85) *Aberrant right hepatics from the superior mesenteric, accordingly, afford an important route of blood supply to the head of the pancreas and should always be looked for in pancreaticoduodenal resections* The distal intrapancreatic portion of the anterior arcade often gives off a small subsidiary arcade which supplies 2 to 3 branches to the ascending duodenum and to the first part of the jejunum then unites with the inferior pancreaticoduodenal branch of the superior mesenteric (Fig 48)

Type II Double Anterior Arcade Often there are two pancreaticoduodenals one arising from the gastroduodenal the other from the right gastroepiploic (Fig 79) After making a loop of a half circle or less on the anterior surface of the head of the pancreas the outer and the inner superior pancreaticoduodenals become merged into a single artery which sinks into the pancreas to join a common inferior pancreaticoduodenal from the superior mesen

teric A posterior branch of this common stem picks up the posterior arcade and supplies the first part of the jejunum (Fig 79) The inner or medial anterior arcade arising from the right gastro epiploic supplies prevailingly only pan creatic branches exceptions being when the pyloric branch arises from it It often unites with the uncinate branch of the dorsal pancreatic which descends behind the portal vein or the superior mesen teric vein after its origin in the celiac region and via another branch it may anastomose with the supraduodenal ar tery of Wilkie (Fig 75)

Common variations of the dual ante rior arcades are cases in which the outer arcade facing the duodenum arises from the gastroduodenal via a superior pan creaticoduodenal which at junction point of the transverse and ascending duodenum sinks into the pancreas then joins an inferior pancreaticoduodenal which arises from the superior mesen teric or from its first jejunal branch (Fig 90) The inner smaller arcade arises from the celiac trunk via a long branch which after passing through the neck of the pancreas crosses the center of the head of the pancreas in front then sinks into the pancreas to join an inferior pancreaticoduodenal arising from the superior mesenteric via the first or second jejunal branch The two inferior pan creaticoduodenals pick up the two pos terior arcades (Fig 90)

In many instances the upper arterial loop after its origin from the superior pancreaticoduodenal courses through the head and the neck of the pancreas and unites with the uncinate branch of the dorsal pancreatic (derived from the splenic the hepatic or the superior mes enteric) or with its transverse pancreatic branch (Fig 61) The lower loop in such cases usually follows Type I It may join an inferior pancreaticoduodenal given off by an aberrant right hepatic derived from the superior mesenteric the aberrant inferior pancreaticoduode nal forming another loop from which branches supply the first part of the je junum (Fig 87)

Quite frequently the dual anterior arcades are made by the same superior pancreaticoduodenal (Fig 74) After leaving the inferior border of the duo denum the superior pancreaticoduode nal swings abruptly to the left in front of the pancreas to join an inferior pan creaticoduodenal from the superior mes enteric then turns to the right again to form a lower paraduodenal loop the beginning of which lies in front of the pancreas However the major part of the lower loop is intrapancreatic and be comes united with a separate inferior pancreaticoduodenal arising from the superior mesenteric at a higher level than that of the upper loop The lower anterior arcade picks up the retroduo- denal arcade (Fig 74)

A branch of the superior pancreatico duodenal may traverse the anterior sur face of the pancreas to join the right gastro epiploic thereby forming an upper small loop the lower being the larger (Fig 70)

Type III Triple Anterior Arcade There are many variations of these a common one being the following (a) a branch of the gastroduodenal after mak ing a complete loop sinks into the pan creas to join the superior mesenteric via an inferior pancreaticoduodenal (b) a branch of the superior pancreaticoduo denal swings to the left forming a half circle then sinks into the pancreas to join the superior mesenteric or the dor sal pancreatic (c) a branch arises from the left side of the gastroduodenal makes nearly a complete loop on the anterior surface of the pancreas then sinks into the pancreas to join the dorsal pancreatic via one of its long pancreatic branches (Figs 60 68)

Type IV Quadruple Anterior Ar cade Since instances of these are rela

tively rare and their manner of formation comprises the variations of anterior arcades described for types I, II and III; further description of the type is unnecessary except for the item that a fourth arcade is present. Usually it is a subsidiary one related to the uncinate branch of the transverse pancreatic branch of the dorsal pancreatic.

Types of Posterior Pancreaticoduodenal Arcades

The posterior pancreaticoduodenal arcade comes to full view when the duodenum is mobilized, i.e., is turned forward to expose its dorsal surface (Figs. 58, 66). It is covered by a fold of connective tissue (Toldt's fascia, the primitive fused mesoduodenum) sufficiently thin to see the course of the arcade and its main branches. It is accompanied by a venous arcade which lies superficial to the arterial arcade and which empties directly into the portal vein, an item to be noted in surgical procedures in this area (Fig. 37).

The posterior pancreaticoduodenal arcade begins with the retroduodenal artery, which, as a rule, is the first left branch of the gastroduodenal given off by the latter above the duodenum and often above the upper border of the head of the pancreas (Fig. 60). Its origin is often cryptic, being hidden by pancreatic tissue. The artery (1 to 3 mm. in width) descends frequently in a tortuous course for a centimeter or more on the left side of the common bile duct; then, after crossing the latter anteriorly, it descends for several centimeters along its right side before swinging to the left and downward to form the posterior arcade. The major portion of the U- or V-shaped arcade lies behind the center of the head of the pancreas. It crosses the intra- (retro) pancreatic portion of the common bile duct posteriorly, thereby placing the latter in an arterial spiral, for at its origin it crossed it anteriorly (Figs. 57, 60). The posterior arcade is situated more cephalad than the anterior and in its course is farther removed from the concave border of the duodenal loop (Fig. 50). It differs somewhat from the anterior arcade in that it often has secondary and tertiary arcades. Ultimately it unites with an inferior pancreaticoduodenal which arises behind the head of the pancreas from the superior mesenteric at a higher level than the inferior pancreaticoduodenal of the anterior arcade (Fig. 50), or it anastomoses with a posterior branch of a common inferior pancreaticoduodenal, the latter receiving both anterior and posterior arcades (Fig. 19).

The main branches arising from the retroduodenal and from the arcades it forms comprise: (1) Several descending branches (2 to 3) to the anterior and the posterior surfaces of the first part of the duodenum. These arise to the right and the left of the common bile duct above the duodenum. Quite frequently one of these branches is the *supraduodenal artery of Wilkie*, distributed to the anterior surface and the upper border of the first inch of the duodenum (Fig. 18). These branches may anastomose with branches from the superior pancreaticoduodenal, the gastroduodenal and with an anterior branch of the dorsal pancreatic which courses to the right. (2) Duodenal branches to the posterior surface of the descending, transverse and ascending duodenum. These vary in number (5 to 10) and in caliber, those given off to the ascending duodenum being the longest. Branches to the descending duodenum cross the intrapancreatic part of the common bile duct posteriorly, even as the main arcade crosses it in its course to unite with the inferior pancreaticoduodenal. (3) Pancreatic branches. These are less numerous and shorter than those of the anterior arcade. They arise from the primary and the subsidiary secondary and tertiary

arcades and exhibit extensive ramifications about the intrapancreatic portion of the common bile duct some branches ascending others descending on it (1) Ascending branches To this category belong one or more branches distributed to the supraduodenal portion of the common bile duct at times supplying the latter to the junction point of the hepatic and the cystic ducts (Fig 15) *In about 4 per cent of the population, the gastroduodenal or its retroduodenal branch gives rise to a cystic artery, either the entire cystic* (Fig 40) *or only its superficial branch* (Fig 47) This anomalous blood supply to the gallbladder should always be borne in mind in cholecystectomies for ordinarily the surgeon does not expect to find a cystic artery coursing caudal to the cystic duct

Occasionally an accessory right hepatic takes origin from the retroduodenal (gastroduodenal) instead of coming from the superior mesenteric (Fig 91) Such an artery crosses the common bile duct anteriorly and is distributed to the fissured area (lateral extension of the porta hepatis) below the gallbladder In its course to the cystic triangle or in the triangle itself it or one of its branches may readily be mistaken for the cystic

A left branch of the retroduodenal coursing behind the common bile duct may unite with a branch of the celiac trunk (Fig 51) the splenic the hepatic the gastroduodenal or with a branch (dorsal pancreatic) from an aberrant right hepatic arising from the superior mesenteric Such a branch may be sufficiently large and tortuous to constrict the common bile duct thereby affording a possible cause of intermittent jaundice (Figs 67 84) In some instances the retroduodenal or one of its descending branches is anastomosed to the right hepatic by means of a large ascending branch (Fig 79) Its anastomosis with the supraduodenal artery of Wilkie is very common the loop thus formed gives off a spray of twigs to the first part of the duodenum to the pylorus and to the adjacent supraduodenal pancreatic tissue (Fig 74)

Variations of the posterior pancreaticoduodenal arcades are somewhat more complicated than those of the anterior They comprise the following types

Type I Single Posterior Arcade The retroduodenal after arising from the right side of the gastroduodenal as its first branch descends behind the first part of the duodenum turns to the left and in so doing makes a U or V shaped loop on the back of the head of the pancreas the loop being more cephalad than that of the anterior It unites with the superior mesenteric via its own inferior pancreaticoduodenal given off at a higher level than the inferior pancreaticoduodenal of the anterior arcade or it joins the superior mesenteric via a common inferior pancreaticoduodenal the latter receiving both arcades (Figs 50 49)

Type II Double Posterior Arcade A common pattern of dual posterior arcades is the one in which the major arcade begins with the retroduodenal and ends in its own or in a common inferior pancreaticoduodenal The second arcade is formed by a branch of the retroduodenal which passes behind the common bile duct to unite with the celiac trunk with an aberrant right hepatic or with a dorsal pancreatic derived from an aberrant right hepatic or from the celiac (Figs 51 55 63 59)

Another variation is the one in which the upper arcade begins with a retroduodenal given off by an aberrant right hepatic derived from the superior mesenteric then loops downward to supply branches to the first and the second parts of the duodenum whereupon it swings upward to join its point of origin from the aberrant right hepatic (Fig 90) A subsidiary lower arcade takes origin from

the upper loop and joins an inferior pancreaticoduodenal given off by the superior mesenteric to its left The lower loop supplies branches to the third portion of the duodenum (Fig 90)

Dual posterior pancreaticoduodenal arcades may be formed by the retroduodenal and a downward extension of the supraduodenal each having its own inferior pancreaticoduodenal derived from an aberrant right hepatic from the superior mesenteric (Fig 82)

Dual posterior arcades commonly are formed by a branch of the main posterior arcade looping upward to join the transverse pancreatic branch of the dorsal pancreatic (Fig 18) or by a branch swinging downward then upward to end in a separate inferior pancreaticoduodenal (Fig 87) One posterior arcade may be formed by the supraduodenal artery of Wilkie the other by a retroduodenal derived from a dorsal pancreatic (Fig 81)

Type III Triple Posterior Arcade Simplest patterns are those in which three posterior branches of a common inferior pancreaticoduodenal from the superior mesenteric swing downward to form three posterior arcades all of which unite with the retroduodenal branch of the gastroduodenal (Fig 69)

More complicated is the following pattern (Fig 63) (1) an arcade supplying the first part of the duodenum formed by a branch of an aberrant right hepatic that swings downward and anterior to the gastroduodenal to join a descending branch of the retroduodenal (2) an arcade supplying the descending duodenum formed by the retroduodenal and a branch of the latter that swings back of the common bile duct and the portal vein to join the aberrant right hepatic (3) an arcade supplying the third part of the duodenum formed by the retroduodenal as it joins the common inferior pancreaticoduodenal i e the posterior branch of the inferior pancreaticoduodenal of the anterior arcade

Type IV Quadruple Posterior Arcade Of these little will be recorded for as with the quadruple anterior arcades they are modifications of Types I II and III with an added arcade formed by a communicating branch of the dorsal pancreatic

No numerical relation exists between the anterior and the posterior arcades Arrangements may be as follows (1) one anterior and one posterior arcade (2) one anterior arcade and two posterior arcades (3) one posterior arcade and two anterior arcades (4) two anterior arcades and two posterior arcades (5) three anterior arcades with one two or three posterior arcades or vice versa three posterior arcades with one two or three anterior arcades

A surgically important vascular arrangement to be remembered in connection with the posterior arcades is the fact *that very often an aberrant right hepatic derived from the superior mesenteric and passing behind the head of the pancreas gives off one or two large inferior pancreaticoduodenals that may receive not only the posterior arcades but also the anterior arcades as well there being little or no connection of the arcades i e, of the blood supply of the head of the pancreas with the superior mesenteric* (Figs 84 88)

Vascularization of Body and Tail

The anterior and the posterior pancreaticoduodenal arcades furnish the major portion of the blood supply to the head of the pancreas *the uncinate process often receiving a branch from the dorsal pancreatic artery* (Figs 63 66) The remaining portion of the organ is supplied by arteries entering the body and the tail of the pancreas at various points and arising for the most part from the splenic trunk relatively few stemming from its terminal divisions The tail of the pancreas may be in contact

arcades and exhibit extensive ramifications about the intrapancreatic portion of the common bile duct some branches ascending others descending on it (1) Ascending branches To this category belong one or more branches distributed to the supraduodenal portion of the common bile duct at times supplying the latter to the junction point of the hepatic and the cystic ducts (Fig 45) *In about 4 per cent of the population, the gastroduodenal or its retroduodenal branch gives rise to a cystic artery either the entire cystic* (Fig 40) *or only its superficial branch* (Fig 17) This anomalous blood supply to the gallbladder should always be borne in mind in cholecystectomies for ordinarily the surgeon does not expect to find a cystic artery coursing caudal to the cystic duct

Occasionally an accessory right hepatic takes origin from the retroduodenal (gastroduodenal) instead of coming from the superior mesenteric (Fig 91) Such an artery crosses the common bile duct anteriorly and is distributed to the fissured area (lateral extension of the porta hepatis) below the gallbladder In its course to the cystic triangle or in the triangle itself it or one of its branches may readily be mistaken for the cystic

A left branch of the retroduodenal coursing behind the common bile duct may unite with a branch of the celiac trunk (Fig 51) the splenic the hepatic the gastroduodenal or with a branch (dorsal pancreatic) from an aberrant right hepatic arising from the superior mesenteric Such a branch may be sufficiently large and tortuous to constrict the common bile duct thereby affording a possible cause of intermittent jaundice (Figs 67 84) In some instances the retroduodenal or one of its descending branches is anastomosed to the right hepatic by means of a large ascending branch (Fig 79) Its anastomosis with the supraduodenal artery of Wilkie is very common the loop thus formed gives off a spray of twigs to the first part of the duodenum to the pylorus and to the adjacent supraduodenal pancreatic tissue (Fig 71)

Variations of the posterior pancreaticoduodenal arcades are somewhat more complicated than those of the anterior They comprise the following types

Type I Single Posterior Arcade The retroduodenal after arising from the right side of the gastroduodenal as its first branch descends behind the first part of the duodenum turns to the left and in so doing makes a U or V shaped loop on the back of the head of the pancreas the loop being more cephalad than that of the anterior It unites with the superior mesenteric via its own inferior pancreaticoduodenal given off at a higher level than the inferior pancreaticoduodenal of the anterior arcade or it joins the superior mesenteric via a common inferior pancreaticoduodenal the latter receiving both arcades (Figs 50 49)

Type II Double Posterior Arcade A common pattern of dual posterior arcades is the one in which the major arcade begins with the retroduodenal and ends in its own or in a common inferior pancreaticoduodenal The second arcade is formed by a branch of the retroduodenal which passes behind the common bile duct to unite with the celiac trunk with an aberrant right hepatic or with a dorsal pancreatic derived from an aberrant right hepatic or from the celiac (Figs 51 55 63 59)

Another variation is the one in which the upper arcade begins with a retroduodenal given off by an aberrant right hepatic derived from the superior mesenteric then loops downward to supply branches to the first and the second parts of the duodenum whereupon it swings upward to join its point of origin from the aberrant right hepatic (Fig 90) A subsidiary lower arcade takes origin from

right gastro epiploic The other right branch via plexiform branches supplies the *uncinate process* of the pancreas which it reaches by passing under the superior mesenteric vein Ultimately it unites with an inferior pancreaticoduodenal Both right branches may participate in the formation of the pancreaticoduodenal arcades often making these double (Figs 68 76)

The characteristic left branch of the dorsal pancreatic—the *transverse pancreatic artery*—courses along the inferior (caudodorsal) border of the body of the pancreas at the tail end of which it communicates profusely with the branches of the a pancreatica magna derived from the splenic and with the a caudae pancreatis derived from the splenic terminals or the left gastro epiploic (Figs 60 66)

A fourth branch of the dorsal pancreatic often descends below the inferior border of the pancreas behind the splenic vein to communicate with the superior mesenteric or with one of its branches (jejunal middle colic or an accessory middle colic) thereby constituting an important *longitudinal collateral pathway between the celiac artery and the superior mesenteric* (Figs 39 69) In some instances this descending branch attained a caliber of 4 mm and was actually the middle colic or an accessory middle colic which instead of stemming from the superior mesenteric arose from the celiac and in its downward course behind the splenic vein gave rise to a pancreatic branch which corresponded to and functioned as the dorsal pancreatic (Figs 40 41)

Collaterals of the Dorsal Pancreatic In the communications it establishes and in the varied types of vessels which may take origin from it the dorsal pancreatic *surpasses* any other artery of its size in the body Through it blood may be routed not only to the pancreas but also to the small and the large intestines (via its branches to the duodenum the jejunum the transverse colon the left colic flexure) to the spleen via the transverse pancreatic and the caudal pancreatic to the stomach and the great omentum via the lower epiploic (omental) arch of Barkow and even to the liver via an accessory hepatic with which it occasionally communicates (Figs 91 100)

As evidenced in 500 dissections the dorsal pancreatic may give rise to the following arteries the aberrant right hepatic the retroduodenal the supraduodenal one or two inferior pancreaticoduodenals one or two jejunal branches a branch to the inferior phrenic *to the ileocolic* to the middle or the left colic to the superior mesenteric and even *to the inferior mesenteric* The right limb of the lower epiploic arc (arcus epiploicus magnus of Barkow) situated in the posterior layer of the great omentum below the transverse colon instead of being linked to the first descending omental (epiploic) branch of the right gastro epiploic may tie up with the *dorsal pancreatic or its transverse pancreatic* branch thereby effecting a collateral pathway for the stomach and the spleen (Fig 100)

Not infrequently the dorsal pancreatic is represented by *two* vessels one arising from the splenic or the celiac the other from a hepatic or an aberrant right hepatic or from the superior mesenteric (Figs 50 84 90 93) Of its diverse communications those made with the superior mesenteric and its branches with the splenic and its branches and with the anterior and the posterior pancreaticoduodenal arcades are the most pronounced and widespread

Surgical Considerations In many instances an *accessory middle colic arises from the celiac the superior mesenteric or the dorsal pancreatic and is known as the artery of Riolan* (Fig 41) Coursing to the left it ramifies in the distal

with the spleen (30 per cent) but more often it is separated from it by an interval of 1 to 4 cm the connection between the two organs being effected by the pancreaticolienal ligament whereby the splenic branches leave the posterior abdominal wall The tail itself may be *flat and thin thick and round tapering and curved upward as a tail*—hence its name At the site of attachment of the transverse mesocolon to the anterior inferior border of the pancreas it splits into two One continues upward to cover the anterior surface of the pancreas the other proceeds downward to become continuous with the peritoneum of the posterior abdominal wall

The pancreatic rami from the splenic comprise two types (a) a variable number (2 to 8) of twiglike branches given off by the splenic at various intervals as it courses along the upper border of the pancreas the twigs in some instances occurring in pairs (b) appreciably large branches with definite distribution and varied connections—viz the dorsal pancreatic (a pancreatica dorsalis) the transverse pancreatic (a pancreatica transversa) the a pancreatica magna and the a caudae pancreatis

Dorsal Pancreatic Artery

The great superior pancreatic artery of Haller (superior pancreatic of Testut) is *generally unknown,* yet is a very important artery (1 to 4 mm in width) Distributed mainly to the dorsal surface of the pancreas in the neck region it often sends branches to the anterior surface as well (Fig 75) Despite its varied origin it is fairly constant in position and readily can be found dorsal to the point where the splenic vein joins the superior mesenteric to form the portal vein the artery in most instances coursing behind the splenic vein (Fig 61)

Known and described by Haller over 200 years ago the dorsal pancreatic is not listed in most texts of anatomy or surgery the obvious reason for this being its *varied origin* In fact from the point of view of origin branching distribution and anastomotic connections *the dorsal pancreatic is the most varied of the celiacomesenteric vessels* In the 200 bodies investigated, the artery had the following origin first part of the splenic 39 per cent (Fig 66) first part of the hepatic or the celiacal right hepatic 12 per cent (Fig 18) first part of an aberrant right hepatic from the superior mesenteric 7 per cent (Fig 86)—a total therefore of 19 per cent from a hepatic celiac 22 per cent (Fig 61) superior mesenteric 14 per cent (Fig 46) gastroduodenal or right gastro epiploic 2 per cent

Eaton (1917) noted that the dorsal pancreatic in many instances was a typical component of a tripod or a tetrapod celiac In the present series the dorsal pancreatic formed a tetrapod type of celiac trunk in 5 per cent of the cases (Fig 80) *Decidedly important from the surgical point of view is the fact that, in some instances the dorsal pancreatic is actually the middle colic or an accessory middle colic which arises from the celiac and in its downward course behind the splenic vein and below the inferior border of the pancreas gives off the dorsal pancreatic branch* (Figs 40 41)

Typically, the dorsal pancreatic arises from the first part of the splenic or the hepatic from the superior mesenteric or from the celiac After giving off a variable number of twigs to the back of the neck and the body of the pancreas some of which emerge to the anterior surface it becomes resolved into two small right branches and one large left branch the latter constituting the transverse pancreatic artery (Fig 66) Of the two right branches one proceeds to the inferior border of the head of the pancreas where it curves forward to the ventral surface and after supplying the latter with several twigs joins the superior pancreaticoduodenal the gastroduodenal or the

branch of the right gastro epiploic (Fig 100)

Frequently the transverse pancreatic is double one arising from the dorsal pancreatic, the other from the gastro duodenal or both may stem from the dorsal pancreatic (Figs 80 77) In one instance a transverse pancreatic of superior mesenteric origin was of such a large size (5 mm in width) as to constitute a *second splenic artery* (a splenica secunda) a large share of the blood coming to the spleen via this route (Fig 121) Instead of stemming from the superior mesenteric directly, the transverse pancreatic may arise via a dorsal pancreatic from the proximal end of an aberrant right hepatic of superior mesenteric origin (Fig 86)

Branches of the Transverse Pancreatic These comprise (1) *Pancreatic rami* given off along its course and which supply the major portion of the pancreatic duct the artery running parallel with the latter for a considerable stretch (Fig 50)

(2) Short and long slender descending *posterior epiploic (omental) vessels* which emerge from the inferior border of the pancreas and course in the posterior layer of the great omentum i e fused transverse mesocolon (pars mesocolonis omenti) (Figs 57 67) These vary in number (4 to 8) and in sites of origin some of them arising from the distal portion of the artery that anastomoses with the a pancreatica magna of splenic origin The posterior epiploics constitute the primitive blood supply to the transverse mesocolon being assisted by branches from the middle colic The short posterior epiploics anastomose with collaterals of the long posterior epiploics sink directly into the anterior surface of the transverse colon or anastomose with the vasa recta of the middle colic or with their arcades The long posterior epiploics anastomose with the ascending branches of the arcus epiploicus magnus of Barkow or with the terminal branches of the anterior epiploics after the latter have left the anterior layer of the great omentum and have curved upward on the posterior layer others anastomose with the vasa recta of the middle colic or with their arcades (Fig 100)

That the posterior epiploics stemming from the transverse pancreatic (at times from the dorsal pancreatic and the a pancreatica magna) should supply the transverse mesocolon is but an embryologic sequence of the fact that the pancreas develops mainly in the posterior layer of the great omentum Accordingly in all instances the anastomoses *of the posterior epiploics with branches* of the middle colic take place on the anterior surface of the transverse colon sequence to the fact that the posterior layer of the great omentum became fused with the anterior layer of the transverse mesocolon and the anterior surface of the transverse colon during the fourth month of fetal life

Since the posterior epiploics stemming from the pancreatic vessels especially the transverse pancreatic are prevailingly filamentlike in size and are distributed mostly to the transverse mesocolon those reaching the transverse colon are not of sufficient caliber to keep this enteric segment viable once the middle colic has been sacrificed The presence of these vessels however in some instances may account for the fact that despite *an extensive devascularization of the transverse colon, gangrene does not occur*

(3) In some instances it gives off the *specific right epiploic artery* that constitutes the right limb of the lower omental arch (arch of Barkow) the usual mode of union of the latter being with a right epiploic stemming from the right gastro epiploic (Fig 100)

(4) *Anastomotic branches* some of which come to the anterior surface of

third of the transverse mesocolon over the so called avascular area of Riolan, ultimately supplying the transverse *colon and the left colic flexure* Interposed between the middle colic and the left colic in the marginal arc of Drummond, its upper (cephalic) main division joins the left branch of the middle colic its lower division joins the ascending branch of the left colic In resections of the transverse colon, *the artery of Riolan should always be looked for and studied as to its relations with the blood supply of the transverse colon, and with that of the pancreas, effected through its dorsal pancreatic branch* The artery of Riolan in some instances is *actually a dorsal pancreatic* of splenic or hepatic origin continued down into the transverse mesocolon to terminate in the transverse colon (Fig 41)

The location and the site of origin of the dorsal pancreatic (behind the junction of the splenic vein with the superior mesenteric vein) should be known to every surgeon when performing a pancreaticoduodenal resection for carcinoma of the head of the pancreas If extirpation of the body of the pancreas is effected to the left far beyond the midvertebral line the dorsal pancreatic is in danger of being severed The remaining part of the body of the pancreas and its tail will thereafter be dependent on the circulatory efficiency of the a pancreatica magna and of minor pancreatic twigs from the splenic (including the caudal pancreatic) as to whether or not it will remain viable That in some instances the cited vessels are not sufficient to furnish an adequate blood supply has been evidenced by two postmortem findings of ischemic necrosis of the body and the tail of the pancreas following pancreatic resection

TRANSVERSE PANCREATIC ARTERY

The transverse pancreatic artery of Haller (1764) (inferior pancreatic of Testut) is a relatively large artery (1 to 2 mm) and in most instances (90 per cent), constitutes the main left branch of the dorsal pancreatic, irrespective of whether the latter artery arises from the splenic the hepatic, the celiac or the superior mesenteric When the dorsal pancreatic arises from the superior mesenteric (14 per cent Fig 50) it ascends to the inferior border of the pancreas and its characteristic transverse pancreatic branch becomes plainly visible in its *initial course as it frequently is when* of higher origin as from the splenic (Fig 14) Remaining superficial for a centimeter or more it courses along the inferior (dorsocaudal) surface of the pancreas to approximately the distal third of the pancreas where at deeper levels its branches unite with those of the a pancreatica magna derived from the splenic trunk and with branches of the a caudae pancreatis stemming variously from the splenic trunk the splenic terminals or the left gastro epiploics (Figs 56 51 52)

In about 10 per cent of the population the transverse pancreatic takes origin from the gastroduodenal the right gastro epiploic or the superior pancreaticoduodenal the respective percentages in this study being 6 per cent 3 per cent 1 per cent (Figs 85 79 86) The artery then represents an enlargement of the right branch of the dorsal pancreatic As such it courses through the entire length of the pancreas sometimes for a distance of 10 cm before it breaks up into its anastomotic branches A long transverse pancreatic of gastroduodenal origin in many instances receives the right limb of the arcus epiploicus magnus of Barkow situated in the posterior layer of the great omentum below the transverse colon the prevailing mode of union of the right limb being its inosculation with the first or the second right epiploic (omental)

the spleen (Fig. 101). In ligations of the splenic artery the caudal pancreatic branch readily may be included causing cyst formations and an ischemic necrosis of the tail of the pancreas.

The Twiglike Pancreatic Rami of the Splenic. In every instance these vary in number (2 to 8), in sites of origin, in distribution and in the variety of communications established. Given off by the splenic at various intervals (often in pairs) along its course they for the most part sink into the substance of the pancreas at various levels; a few ramify superficially on its anterior surface where they form looplike anastomoses with neighboring splenic rami. In the interior of the pancreas they communicate with branches from the supraduodenal, the retroduodenal, the gastroduodenal, the superior pancreaticoduodenal and the right gastro-epiploic to the right, and with branches from the dorsal pancreatic, the a. pancreatica magna and the caudal pancreatic to the left. Aside from establishing numerous communications inside the pancreas and on its superficial surface by their plexiform arrangement, the splenic rami are not of sufficient size to afford the pancreas a viable blood supply when the major pancreatic arteries have become occluded or have been severed.

Collateral Pathways

Numerous, diversified and far-reaching are the collateral pathways that can be established by the pancreatic vessels. *Nearly all of the collateral routes effected by the splenic circulation are directly or indirectly related with the arteries of the pancreas.* The three most important routes comprise: (1) the circulus transpancreaticus longus (Fig. 56), (2) the circulus pancreatico-duodenalis (Fig. 52), (3) the arcus epiploicus magnus of Barkow (Fig. 100). A description of these routes is given in Chapter 13.

As a surgical precaution, it should be emphasized that the anterior and the posterior pancreaticoduodenal arcades and the anastomoses which they establish vary in each instance. Because of this fact Wilmer (1941) claimed that ligation of any plexus vessel to control bleeding in a massive hemorrhage from the posterior duodenal wall is futile. Ziegler (1942) called attention to the frequency of a *high* origin of the inferior pancreaticoduodenal from the superior mesenteric instead of a low one as usually described. Ligation of such a high inferior pancreaticoduodenal would seriously endanger the viability of the third part of the duodenum supplied by this artery.

But a decade ago, according to Berg (1948), surgical procedures on the pancreas were few and very conservative, the main reason for this situation being the diversity and the complexity of the arterial blood supply of the organ. With a newer knowledge of the variational anatomy of the pancreatic arteries presented in this atlas, the lines written by Halsted (Johns Hopkins Hosp. Rep. 19, 71) on the "operative story of goiter" may well be cited as equally applicable in pancreatic resections, to wit:

In a wound that is perfectly dry and in tissues never permitted to become even stained by blood, the operator, unperturbed, may work for hours without fatigue. The masterfulness in controlling haemorrhage gives to the surgeon the calm which is so essential for clear thinking and orderly procedure at the operating table.

the pancreas where they communicate with anterior branches from the dorsal pancreatic the splenic rami the a pancreatica magna the gastroduodenal and even the supraduodenal (Fig 71)

(5) *A colic branch* which occasionally courses directly to the left colic flexure it being but a variant of the long posterior epiploics (Fig 11)

Arteria Pancreatica Magna

This short and stout artery first described by Haller (1764) varies from 2 to 1 mm in width and is the *largest* pancreatic branch of the splenic It arises from the distal third of the splenic artery shortly before the latter divides into its superior and inferior terminal branches (Fig 62) In the majority of instances it takes origin from the splenic artery while the latter is still behind or is embedded in the pancreas or at a point where the splenic has become free at the upper border of the pancreas covered only by a peritoneal fold (plica splenica) of the posterior abdominal wall When the splenic is markedly tortuous and thrown in loops and coils it often stems from a distal loop above the pancreas and is visible in its initial course (Fig 130)

In the pancreas the a pancreatica magna takes an oblique frequently tortuous course toward the left and breaks up into numerous branches which toward the right anastomose with branches of the transverse pancreatic the dorsal pancreatic the small rami previously given off by the splenic while toward the left it anastomoses with branches of the a caudae pancreatis derived from the splenic terminals or from the left gastro epiploic In some instances one of its branches leaves the inferior border of the pancreas to become a posterior epiploic (omental) artery that ramifies in the transverse mesocolon and when extended to the left may reach the left colic flexure as a vessel of such appreciable size as to necessitate its ligation when removing the transverse colon

In resections of the pancreas the a pancreatica magna should be spared wherever possible, it being the main blood supply to the tail of the pancreas Ligations of the splenic should never involve the distal end (tail) of the pancreas lest the artery be destroyed Thrombosis in the portal vein postoperative hemorrhagic pancreatitis fat necrosis cysts fistulization—these are further possible sequences to the inclusion of the pancreatic tail in splenic ligatures as emphasized by Henschen (1928)

Arteria Caudae Pancreatis

This artery was first described by Winslow (1793) As implied in the term it supplies the tail end of the pancreas the configuration and the volumetric proportion of which determine the artery s site of origin and its pattern of distribution Predominantly it arises from the left gastro epiploic less frequently from the splenic or the splenic terminals (Figs 59 61 62) When the tail of the pancreas is in contact with the hilus of the spleen (30 per cent) the artery is very short plunging immediately into the pancreas When the tail is curved upward and abuts a splenic terminal the artery is frequently double one arising from the splenic terminal the other from the left gastro epiploic In some instances the artery has a triple origin one vessel arising from an inferior lienal polar branch

Within the tail of the pancreas the a caudae pancreatis communicates with branches of the a pancreatica magna the transverse pancreatic and twigs derived from the splenic It is commonly the specific source of blood supply for a pea sized accessory spleen located in the pancreaticolienal ligament or in a pitlike depression on the hilar surface of

from the left gastric (11 5 per cent), or partially, when an accessory left hepatic arises from this source (11 5 per cent) This important life sustaining fact should always be borne in mind Previous to ligating the left gastric it is but careful surgery to ascertain defi nitely whether the left gastric via a left hepatic branch is the only blood supply to the left lobe of the liver Postmortem examinations following gastric resection have shown that the immediate cause of the death of the patient was due to ischemic necrosis of the left lobe of the liver the necrosis being a direct result of ligating a left gastric which supplied the left lobe of the liver Long ago Wil liam Mayo (1915) called attention to the arterial hazards in splenectomies emphasizing in particular the cryptic position the filamentous character and in some instances the extremely long course of the superior splenic polar ar tery Careless operative inattention to this artery may result in fatal hemor rhage as Mayo admitted for one of his cases

The truth of the matter is that varia tions in the anatomic structures espe cially arterial blood supply and existent pathways for collateral circulation are not sufficiently stressed in anatomic teaching leaving to the surgeon too great freedom in elective ligation and sacrifice of blood vessels The general ized opinion gathered from standard textbooks of anatomy that the blood supply of the stomach is a very simple one and fairly uniform has led many surgeons to follow routine procedures in standard gastric resections without re gard to a variant blood supply Not familiar with the multiplicity of arterial variations they unguarded have pro ceeded with the interference of blood supply leaving it to chance as to what role anomalies in arteries and in their disposition and anastomoses might play William Stewart Halsted pioneer Amer ican surgeon repeatedly emphasized the truism that the best method to minimize and avoid injury to blood vessels is to know them and to know their variations Only thus can laceration of vessels and devascularization of tissue be prevented

Lastly the anatomic terms applied to some vessels are far too cumbersome and confusing to be definitely ear marked to the surgeon A typical in stance of this is the designation of the artery that forms an extensive arcade on the back of the duodenum and the head of the pancreas as the posterior superior pancreaticoduodenal artery when the short and simple term retro duodenal artery would indelibly im press this artery and its relations with the biliary ducts upon the mind of every surgeon In certain regions markedly in the supramesocolic region arterial variations are so numerous and compli cated that they offer as Sir Arthur Keith phrased it a definite challenge to mem ory This fact should not make the anatomist or the surgeon unwilling to take the time or to make the effort required to familiarize himself with ob served anatomic variations for if ana tomic variations are worth knowing at all they are worth knowing as accurately and extensively as possible

As previously stated arterial like other anatomic variations cannot be ignored for the risk of depriving an organ or a part of an organ of its proper blood supply is too great Arterial varia tions are verifiable factors in human constitution that can be observed time and time again They can be statisti cally estimated by dissection of a large series of bodies and should accordingly be summed up in the lowest common denominators readily available to both the anatomist and the surgeon With newer growing knowledge anatomy takes on a richer and more complete sig nificance as a science and as a guide to surgical procedure and operative tech nic With this in mind the following account of the varied character of the

Since the left gastric may give off a large branch to the liver it merits the name left gastrohepatic (Mereturque nomen gastrohepaticae sinistrae) Tabulae arteriae coeliacae

—HALLER February 20 1745

10

Blood Supply of the Stomach and the Esophagus

Blood Supply of the Stomach

In a previous chapter it was shown that an adequate and extensively experienced knowledge of the amazing variability of the hepatic the cystic and the pancreaticoduodenal arteries and their relations to the gallbladder and the biliary ducts was an absolute requisite to avoid hazards which Sir Arthur Keith said were ever rampant in cholecystectomy and pancreaticoduodenal resections

Surgically considered a comparable dire need of exact and extensive anatomic knowledge exists today as regards the varied patterns of the arterial blood supply to the stomach and the esophagus for the textbook description and the general anatomic concept of the vascularization of these organs are markedly inadequate and misleading[1]

[1] It might be recalled here that it was before the Philadelphia Academy of Surgeons that William J Mayo on May 11 1903 in the presence of an august body gave a paper entitled A Review of 303 Operations Upon the Stomach and the First Part of the Duodenum the surgeons invited to discuss the paper being Drs Finney Murphy and Moynihan Shortly thereafter (1905) William Mayo was awarded fellowship in the Royal College of Surgeons of Edinburgh the only other two American surgeons so honored at the time being William W Keen of Jefferson Medical College and William S Halsted of Johns Hopkins University It was William Mayo who operated on White Frazier and Keen all professors of surgery While convalescing from his abdominal operation and after having witnessed the pioneer work of the Mayo brothers Keen advised William Mayo with these words You ought to write more As we all know he subsequently did write extensively on his work

Success in the shifting of the stomach from the abdominal cavity into the thoracic cavity in operative procedures for esophageal malignancy depends on the re establishment and the maintenance of an adequate blood supply and on a reduction of tension at the site of anastomosis Every gastric resection total or subtotal, every esophagojejunostomy or gastrojejunostomy carries with it the danger of leaking and bleeding from the site of anastomosis In every instance *closure of the duodenal stump is a hazardous procedure* from the point of view not only of injuring the common bile duct but also of creating conditions permitting and favorable to recurrent and incessant hemorrhage An excessive stripping of the retroduodenal areolar tissue and its contained blood vessels (especially the retroduodenal arcade) at the site of closure of the sectioned duodenum may be the direct cause of an ischemic diastasis of the suture lines with a resultant fatal sloughing and blowing out of the duodenal stump albeit the latter complication is usually ascribed to abnormal physiologic processes Inflammation and contraction of the pylorus and the proximal duodenum are constant dangers in gastrectomies (Levy 1950) *In about one fourth of all subjects, a gastric resection will involve the blood supply of the left lobe of the liver, either in its entirety when the left hepatic artery is replaced, i e, takes origin*

from the left gastric (11 5 per cent), or partially, when an accessory left hepatic arises from this source (11 5 per cent) This important life sustaining fact should always be borne in mind Previous to ligating the left gastric it is but careful surgery to ascertain definitely whether the left gastric via a left hepatic branch is the only blood supply to the left lobe of the liver Postmortem examinations following gastric resection have shown that the immediate cause of the death of the patient was due to ischemic necrosis of the left lobe of the liver the necrosis being a direct result of ligating a left gastric which supplied the left lobe of the liver Long ago William Mayo (1915) called attention to the arterial hazards in splenectomies emphasizing in particular the cryptic position the filamentous character and in some instances the extremely long course of the superior splenic polar artery Careless operative inattention to this artery may result in fatal hemorrhage as Mayo admitted for one of his cases

The truth of the matter is that variations in the anatomic structures especially arterial blood supply and existent pathways for collateral circulation are not sufficiently stressed in anatomic teaching leaving to the surgeon too great freedom in elective ligation and sacrifice of blood vessels The generalized opinion gathered from standard textbooks of anatomy that the blood supply of the stomach is a very simple one and fairly uniform has led many surgeons to follow routine procedures in standard gastric resections without regard to a variant blood supply Not familiar with the multiplicity of arterial variations they unguarded have proceeded with the interference of blood supply leaving it to chance as to what role anomalies in arteries and in their disposition and anastomoses migh play William Stewart Halsted pioneer American surgeon repeatedly emphasized the truism that the best method to minimize and avoid injury to blood vessels is to know them and to know their variations Only thus can laceration of vessels and devascularization of tissue be prevented

Lastly the anatomic terms applied to some vessels are far too cumbersome and confusing to be definitely earmarked to the surgeon A typical instance of this is the designation of the artery that forms an extensive arcade on the back of the duodenum and the head of the pancreas as the posterior superior pancreaticoduodenal artery when the short and simple term retroduodenal artery would indelibly impress this artery and its relations with the biliary ducts upon the mind of every surgeon In certain regions markedly in the supramesocolic region arterial variations are so numerous and complicated that they offer as Sir Arthur Keith phrased it a definite challenge to memory This fact should not make the anatomist or the surgeon unwilling to take the time or to make the effort required to familiarize himself with observed anatomic variations for if anatomic variations are worth knowing at all they are worth knowing as accurately and extensively as possible

As previously stated arterial like other anatomic variations cannot be ignored for the risk of depriving an organ or a part of an organ of its proper blood supply is too great Arterial variations are verifiable factors in human constitution that can be observed time and time again They can be statistically estimated by dissection of a large series of bodies and should accordingly be summed up in the lowest common denominators readily available to both the anatomist and the surgeon With never growing knowledge anatomy takes on a richer and more complete significance as a science and as a guide to surgical procedure and operative technic With this in mind the following account of the varied character of the

blood supply of the stomach and the esophagus will be given

For the present chapter the author can supply informative data on the vascularization of the esophagus only as regards its abdominal i e infradiaphragmatic portion it alone having been included in the 200 dissections of the supramesocolonic organs A detailed description of the varied blood supply of the entire esophagus as ascertained by Shapiro and Robillard (1950) and by Swigart Siekert and Hambley and Anson (1950) will be given later

Observations

The blood supply of the stomach and the esophagus is accomplished by the following 12 arteries (1 and 2) the left and the right gastrics with branches to the anterior and the posterior surfaces (3 and 4) the right and the left gastro epiploics with branches to the anterior and the posterior surfaces (5) the splenic by a variable number (2 to 10) of short gastric branches (arteriae gastricae breves) arising from the distal third of the splenic trunk its terminal divisions or the left gastro epiploic and reaching the cardia through the phrenicogastric and the lienogastric ligaments (6) the gastroduodenal by direct small branches at times by a large pyloric branch (7) the superior pancreaticoduodenal by short twigs frequently by a large pyloric branch which may be shifted to the right gastro epiploic (8) the supraduodenal artery of Wilkie *which in addition to supplying the first* part of the duodenum often sends one or more branches to the pylorus (9) the retroduodenal which in its tortuous descent along the left side of the common bile duct to reach the back of the pancreas and the duodenum frequently gives off one or more pyloric branches which in some instances unite with the supraduodenal and the right gastric (10) the transverse pancreatic which when it arises from the gastroduodenal the superior pancreaticoduodenal or the right gastro epiploic (10 per cent) may give one or more twigs to the pylorus (11) the dorsal pancreatic the right branch of which anastomoses with the pancreaticoduodenal and in so doing sends some branches to the pylorus (12) the left inferior phrenic which in its course to the diaphragm in most instances gives off one or more direct recurrent branches to the cardio esophageal end of the stomach

A dozen arteries are therefore more or less regularly involved in typical patterns of the stomach s blood supply Of these the first six are the primary arteries the last six secondary In atypical patterns blood may reach the stomach via the following additional vessels accessory left gastrics from the celiac the splenic the left inferior phrenic the hepatic trunk or the left hepatic Aberrant left hepatics (3 to 5 mm) arising from the left gastric (whether of the replaced or the accessory type) invariably give off 1 to 3 cardio esophageal branches and in some instances a major accessory left gastric that reaches the body of the stomach (Fig 48) In contrast with the preceding a normal left gastric i e one arising from the celiac rarely gives off an accessory left gastric (Fig 63) When as is often the case an arcade is established between the left gastric and the celiacal left hepatic by a small artery coursing along the peripheral edge of the lesser omentum that anastomosing artery invariably gives off 2 to 4 twig size cardio esophageal branches (Figs 53 79 87)

Accessory left gastric arteries may be classified into two types (1) those that are distributed primarily to the anterior surface of the stomach and arise from the hepatic the celiac or a left hepatic aberrantly derived from the left gastric (Figs 48 51 63 83) (2) those found behind the stomach distributed to its

posterior surface and arising from the splenic anywhere along its course, frequently from the superior splenic polar artery (Fig 50 57). The accessory left gastric arising from the splenic (a gastrica posterior of Haller) may readily be seen when the gastrocolic ligament is severed and the stomach is lifted up. It courses behind the bursa omentalis and *reaches the stomach via the phrenicogastric* ligament whereby the stomach is placed outside the omental bursa or sac. The artery is often of such a large size (2 to 3 mm) and supplies such an extensive area of the posterior surface of the fundus of the stomach as to justify its designation as a separate artery—viz the ramus esophagastricus posterior ascendens (Figs 50). Dividing into 3 to 4 branches it frequently gives off a branch to the superior pole of the spleen. In one case both types of accessory left gastrics were present, one coming from the splenic, the other from an accessory left hepatic (Fig 65). The incidence of an accessory left gastric arising from the celiac axis is relatively frequent (Figs 19 45 51).

The terminal branches of the left gastric anastomose with (1) short gastrics from the splenic terminals or with branches from the superior splenic polar, (2) short gastrics from the left gastro epiploic, (3) cardio esophageal branches from the left inferior phrenic, the aberrant left hepatic from the left gastric, the accessory left gastric from the left hepatic, (4) early ascending cardio esophageal branches from the left gastric or the celiac, (5) descending branches from the thoracic esophageal branches. Anastomoses occur on both the anterior and the posterior surfaces of the stomach and the esophagus; those present about the esophagus and furnished by the left inferior phrenic are predominantly posterior in position, those located in the fundic region and supplied by an accessory left gastric derived from a left hepatic arising from the left gastric are mainly anterior. Commonly the posterior surface of the fundic region of the stomach is the site of an extensive anastomosis between the short gastrics from the splenic terminals and the cardio esophageal branches from the left inferior phrenic (Fig 63).

The topic of anastomosis between the various gastric arteries will be discussed in detail later. For the present it should be emphasized that arterial anastomosis about the cardio esophageal end of the stomach is extremely variable. It may be very extensive but it may also be very sparse. The surgical implications of these variations in arterial anastomoses are of paramount importance and may offer an explanation why some gastric and esophageal resections have an unexpected, delayed fatal issue while the majority come through with re-establishment of circulation.

Gastric Arteries Statistically and Relationally Considered

Left Gastric. In a statistical study of 200 subjects the left gastric arose from the celiac in 180 cases (90 per cent). Invariably much larger than the right gastric, its point of origin from the celiac varied from the level of the aorta to the distal end of the celiac. Most commonly it arose as the first branch of the celiac at the latter's middle (Fig 60). In 25 per cent the left gastric took origin from the distal end of the celiac along with the hepatic and the splenic, thus forming the tripod of Haller (Fig 58). In many instances (5 per cent) the dorsal pancreatic and occasionally the middle colic or an accessory middle colic arose from the same common distal end of the celiac, thus making the latter a tetrapod (Figs 40 74).

The width of the left gastric varied from 2 to 8 mm, most commonly being

4 to 5 mm as seen from the following table

Width in mm	2	3	4	5	6	7	8
Times	1	1	19	12	9	3	2

As previously shown in about one half of 200 subjects the celiac artery was incomplete, one or more of its branches arising from the aorta either independently of or in conjunction with one of its celiac branches The celiac hepatic often supplied only the right or the left lobe of the liver In such cases the missing hepatic was replaced from some other source the right hepatic predominantly from the superior mesenteric (12 5 per cent) the left hepatic from the left gastric (11 5 per cent) (Figs 84 48) The left gastric often (11 5 per cent) furnished an accessory left hepatic i e a branch to the left lobe of the liver which was additive to the left hepatic arising from the celiac (Fig 49)

Because of the frequent origin of a left hepatic (replaced or accessory) from the left gastric the early anatomists (those of the seventeenth and the eighteenth centuries) followed the nomenclature of Haller and designated the left gastric as the gastrohepatic artery a term still currently used in French texts In view of the fact that the left gastric participates in the blood supply of the liver in one fourth of the population (23 per cent in this series of 200 specimens) the term gastrohepatic artery is much more comprehensive and explicative of factual arterial arrangement than is the term left gastric

The varied patterns of the celiac axis as observed by the author in 200 specimens were classified into seven types These need not be discussed again but should be referred to for orientation as to aberrant modes of origin of the left gastric Atypically the left gastric arose (a) separately from the aorta (2 5 per cent Fig 69) the other celiac branches coming from a hepatolienal (2 per cent Fig 69) or a hepatolienomesenteric trunk (0 5 per cent Fig 56) (b) from a lienogastric trunk (1 5 per cent Fig 38) the hepatic coming from the aorta (2 per cent Fig 93) or from a hepatomesenteric trunk (2 5 per cent Fig 38) (c) from a hepatogastric trunk (1 5 per cent Fig 67) the other two celiac branches forming a lienomesenteric trunk Three odd derivations of the left gastric were noted—viz, origin from the splenic from the left hepatic and from a replaced right hepatic (Figs 50 54)

Accessory left gastrics arose from the splenic (6 per cent) the left hepatic (3 per cent) the celiac (2 per cent) and in one case from the hepatic trunk The accessory left gastric from the splenic—the ramus gastroesophagus posterior ascendens—with the size of 1 to 3 mm reaches the fundic region posteriorly The accessory left gastric from the left hepatic is usually smaller (3 mm) than its counterpart the aberrant left hepatic from the left gastric (3 to 5 mm) and in some instances is double (Fig 48) The one from the celiac is an independent artery and because of its threadlike size may be a bleeder in operative procedures (Fig 45) Aberrant left hepatics arising from the left gastrics and varying from 3 to 5 mm in width were noted in 46 cases (23 per cent) of which 11 5 per cent (23 cases) were replaced left hepatics and 11 5 per cent (23 cases) were accessory left hepatics (Figs 48 49) The left inferior phrenic in most instances supplied cardioesophageal branches and in 4 per cent took origin from the left gastric (Figs 56 74)

In view of the precarious anatomic relationship of the left gastric to the stomach and to the liver in those cases where an aberrant left hepatic arises from a left gastric (23 per cent in this series Adachi 20 per cent) gastric re

sections and in particular, transpositions of the stomach into the thoracic cavity for esophageal malignancy should be preceded by an exploratory examination as to what type of left gastric is present. If a replaced, i.e., substituted, left hepatic arises from the left gastric, the latter should be ligated distal to the point of origin of the replaced left hepatic, it being the only supply to the left lobe of the liver. Were the entire blood supply to come from the left gastric, as observed in one instance in this series where the hepatic trunk came from the left gastric, faulty ligation of the left gastric would result in the immediate death of the patient (Fig. 20).

The mode of branching and the distribution of the left gastric follow a fairly uniform pattern. At its origin from the celiac, the left gastric at first lies behind the posterior layer of the omental bursa and is accordingly covered by the secondary parietal peritoneum of the posterior abdominal wall. As in this position it courses forward, upward and to the left in a gentle curve, it raises a crescentic ridge of peritoneum, the left gastropancreatic fold (plica), whereby it reaches the anterior wall of the omental bursa along with the coronary vein. The crescentic peritoneal fold containing the left gastric constitutes the left wall of the omental isthmus, the right wall of which is formed by a comparable peritoneal fold (hepatopancreatic plica) made by the common hepatic as it courses toward the hepatoduodenal ligament. The isthmus is the passageway from the omental vestibule (portion of the bursa under the lesser omentum) to the retrogastric space (Fig. 1).

When the left gastric reaches the area uncovered by peritoneum near the cardiac end of the stomach, it abruptly turns caudally, i.e., reverses its direction, and passes between the layers of the lesser omentum. As a rule, the left gastric divides into two main branches: an anterior branch distributed to the anterior surface of the stomach in 2 to 3 main subdivisions, and into a posterior branch which in its course along the lesser curvature gives branches to the posterior surface and in most cases anastomoses with the right gastric (Fig. 77). Before dividing into its 2 terminal branches, the left gastric supplies the cardio-esophageal end of the stomach either by a single large branch which subdivides or by 1 to 3 branches successively given off by the main vessel. In some instances, where there is no anastomosis between the left gastric and the right gastric, the secondary divisions of the two vessels enter the muscular coat of the stomach, anastomosis being effected in the submucous layer (Fig. 50). When an aberrant left hepatic arises from the left gastric, it is given off by the latter just proximal to the point where it bends caudally and divides into its two main branches. The aberrant left hepatic, 3 to 5 mm. in size, courses upward (6 cm.) near the esophagus between the two layers of the lesser omentum, crosses the caudate lobe and enters the liver via the fissure for the ligamentum venosum. In its upward, often hidden, course along the peripheral edge of the lesser omentum, it gives off 1 to 3 cardio-esophageal branches which in their distribution on the anterior and the posterior surfaces of the esophagus and the cardia anastomose at various points with esophageal branches from the thoracic region and with branches given off by the left inferior phrenic. Cases were observed in which the hepatic branch of the left gastric (i.e., the replaced left hepatic) was larger (5 mm.) than the main vessel going to the stomach (3 mm.) (Fig. 48).

Frequently, the left inferior phrenic or the right inferior phrenic takes origin from the left gastric, a fact of surgical significance in ligating the artery at a

proper point to preserve the blood supply to the diaphragm (Fig 71) Separate origin of the two vessels from the left gastric was strikingly the case when the latter arose separately from the aorta (Figs 56 73)

Right Gastric In 200 specimens the right gastric was invariably much smaller than the left gastric its average diameter being 2 mm as compared with that of the left gastric (4 to 5 mm) Despite its filamentous character and its cryptic course in certain instances it was identified in all cases

Obviously the varied mode of origin of the right gastric is due to the varied mode in which the hepatic gives off its main branches Most commonly the right gastric arises from the hepatic trunk shortly after the latter has given off the gastroduodenal and before it divides into its main right and left branches (Figs 51 60) When origin of the right gastric is delayed it arises from the proximal portion of the left hepatic (Fig 50) when advanced it arises from the proximal portion of the gastroduodenal or from the hepatic trunk before the latter is given off (Figs 62 66) Quite frequently three or four of the main branches of the hepatic (right and left hepatic gastroduodenal right gastric) arise from the hepatic at the same point or in close proximity to one another (Fig 74) When the entire hepatic arises from the superior mesenteric the mode of origin of the right gastric follows the usual pattern (Fig 53) When only the right hepatic is derived from the superior mesenteric the left hepatic after giving off the gastroduodenal usually furnishes the right gastric (Fig 82) Occasionally the right gastric and the middle hepatic arise from the hepatic by a common trunk (Fig 59) A direct origin of the right gastric from the aorta or the celiac was not observed As opposed to the frequency of the two left gastrics (accessory or dual) two right gastrics were never encountered

In the 200 bodies statistically estimated, the right gastric arose as a branch of the following arteries (1) the common hepatic in 80 cases (10 per cent) including hepatic trunks derived from the superior mesenteric or the aorta (1 5 per cent) (2) the left hepatic in 81 cases (40 5 per cent) including replaced left hepatics from the aorta and the superior mesenteric (2 per cent) (3) the right hepatic in 11 cases (5 5 per cent) including replaced right hepatics from the aorta the superior mesenteric and the left gastric (1 5 per cent) (4) the middle hepatic in 10 cases (5 per cent) (5) the gastroduodenal in 16 cases (8 per cent) In 1 case the right gastric arose as a branch of the retroduodenal and in 16 cases (8 per cent) it gave off the supraduodenal artery of Wilkie the significance of which will be discussed shortly (Fig 19) It is interesting to note that while the constancy of origin of the left gastric from the celiac amounted to 90 per cent the constancy of origin of the right gastric fell to 80 per cent the common hepatic and the left hepatic sharing the site of origin in about equal proportion

Typically the right gastric descended to the pylorus between the two layers of the lesser omentum often giving off branches to this region of the stomach before reaching the lesser curvature Approaching the latter it turned to the left and ascending from right to left anastomosed in most instances with the posterior branch of the left gastric The line of anastomosis between the right and the left gastric vessels often fell behind the peripheral edge of the lesser curvature and could therefore not be ascertained until the lesser omentum was dissected (Fig 76)

In addition to supplying an extensive area of the stomach along the lesser curvature with anterior and posterior

branches, the right gastric in many instances served as a primary and supplementary route of blood supply not only to the gut but also to the liver. Through the supraduodenal artery of Wilkie that took origin from it in 19 cases (8 per cent) it supplied the first part of the duodenum and accordingly functioned as a primary route of blood supply to this section of the gut (Fig. 59). Through the middle hepatic that took origin from it in 10 cases (5 per cent) it supplied the quadrate lobe of the liver (Fig. 59). Formation of a common stem for the right gastric and the middle hepatic and emergence of this common stem from the gastroduodenal came about in cases where the right hepatic was derived from the aorta, the gastroduodenal taking origin directly from the superior mesenteric (Fig. 67). A combined, i.e., common origin of the right gastric and the middle hepatic was likewise brought about when both the right and the left hepatics were replaced (Figs. 13, 55).

The functional role of the right gastric as a supplementary blood supply was accomplished by its anastomotic branches. Right branches of the right gastric often communicated with descending branches of the retroduodenal, these being given off by the latter above the duodenum and before it reached the back of the head of the pancreas (Fig. 51). The supplementary arcade thus formed by branches from the right gastric, the retroduodenal, assisted at times by branches from the supraduodenal, was the source of a copious blood supply to the critical transition zone between the pylorus and the first part of the duodenum. Not uncommonly a fountainlike spray of fine arterial twigs emerging from the arcade became distributed to this region (Fig. 59).

The varied and precarious blood supply to the critical transition zone between the pylorus and the duodenum might have some clinical significance as to formation of peptic ulcers and the liability to leakage after suture of the first part of the duodenum. In his study of the supraduodenal artery, Wilkie (1911) correlated the tendency of ulcers to perforate the upper portion of the duodenum just beyond the pylorus with the paucity of blood supply to the first half inch of the duodenum, it being supplied by the supraduodenal.

This hypothesis was substantiated by Reeves (1920) on the basis of observations made on sectioned material. Since in the first inch of the duodenum the submucous plexus contained fewer arteries than in any other region and since the plexus vessels along the lesser curvature were not as freely anastomosed as in other parts of the stomach, Reeves concluded that a slight deviation from the normal blood supply might contribute to peptic ulcer.

Interesting here is the observation of Barlow, Bentley and Walder (1951) that in the region of the lesser curvature the mucosal arteries do not arise from a plexus of vessels within the stomach wall but have their origin outside the stomach—i.e., they arise directly from the right and the left gastric arterial chains. Anatomically considered, according to these authors, there are no end arteries in the stomach, their free anastomosis being their most noted feature. Further items of their investigative results have already been given in the literature (page 18).

While this present investigation cannot substantiate Wilkie's contention from a clinical point of view, it does confirm his opinion that the first part of the duodenum has a markedly varied blood supply, quantitatively considered, and that the transition zone between the pylorus and the duodenum is indeed in some instances a critical one, as *first* pointed out by William Mayo. However, the supraduodenal artery is defi

nitely *not an end artery*, as claimed by Wilkie, for in many bodies examined in this series it definitely communicated with branches from the right gastric, the gastroduodenal, the hepatic or its branches, the dorsal pancreatic and the superior pancreaticoduodenal (Figs. 59, 51, 75, 93, 70).

The problem of a causative correlation between the paucity or insufficiency of blood supply and the site of duodenal ulcers merits further investigation, for anatomically considered, the transition zone in many cases has a poor blood supply. The problem should be studied on the basis of an extensive investigation of pathologic material obtained at autopsy. Likewise in need of investigation is a statistical estimate of factual relationship between mortality rate and anatomic conditions and arrangement of arterial blood vessels modified and created during gastric resections. *The study might throw some light on the much debated, as yet unknown, distressing causative factor of blowing out of the duodenal stump following operative procedures to remove bleeding duodenal ulcers.* Not all deaths following cholecystectomies or gastric resections for duodenal ulcers are due solely to unexpected physiologic complications. Many fatal issues may have a direct anatomic basis (viz., devascularizing the viscus to a degree incompatible with reparative processes, with resultant ischemic necrosis). Time and time again it has been proved on reopening the abdomen that a severe injury to the common hepatic duct made during operation was the direct cause of postoperative leakage of bile. What of vascular insufficiency, i.e., of interfering with arterial arrangement to such an extent that an adequate circulation cannot be re-established, leaving the part without a blood supply?

Gastroduodenal. Accurate and extensive knowledge as regards the topographic relations, the varied character, the mode of origin and the branching of the gastroduodenal is extremely important to the surgeon. Foremost are its relations to the biliary system. Predominantly located to the left of the common bile duct, it frequently crosses the supraduodenal part of the common duct anteriorly or posteriorly. Its characteristic first branch—the retroduodenal—comes in relation with the common duct twice—viz., at its origin, where it crosses the supraduodenal portion of the common duct anteriorly, and at its end, where it forms the posterior pancreaticoduodenal arcade situated on the back of the head of the pancreas and on the back of the intrapancreatic part of the common duct. In its downward course from the gastroduodenal, the retroduodenal accordingly makes a spiral about the common duct, supplying it as it does, and may readily be injured in operative manipulations of the duct (Figs. 57, 60).

In resections of the head of the pancreas, in operative procedures for gastric and duodenal resections, the gastroduodenal is always involved. In each instance, it should be studied with the utmost vigilance, for an unwarranted ligation of it may have dire results for other organs—e.g., for the transverse colon when the middle colic arises from it (2 cases) (Fig. 51); for the gallbladder when the entire cystic artery takes origin from it (3 cases) (Fig. 46); for the quadrate lobe of the liver and the lesser curvature of the stomach when the middle hepatic and the right gastric arise from it via a common stem or as separate branches (2 cases) (Fig. 67).

Judged from this series of 200 bodies, the gastroduodenal arises in about one half of the population from the hepatic, usually at a point midway between the latter's origin from the celiac and its division into right hepatic and left hepatic branches. The unbranched hepatic trunk is more frequently long than short, and in its initial course from the

celiac lies behind the parietal peritoneum Like the left gastric the hepatic must pass from behind the back wall of the omental bursa to the latter s anterior wall made by the lesser omentum It does this by raising a fold of peritoneum the hepatopancreatic plica whereby it enters the hepatoduodenal ligament or the dense free edge of the lesser omentum

After its typical origin from the hepatic the gastroduodenal descends behind the first part of the duodenum to the lower border of the pylorus where it divides into the right gastro epiploic and the superior pancreaticoduodenal a third branch of varied size often being given off at the division point to wit the pyloric branch (Figs 68 71 77) In some instances a fourth branch arises from the distal end of the gastroduodenal viz the transverse pancreatic (Fig 72) Because of its varied length (1 to 6 cm in this series) the division point of the gastroduodenal into its terminal branches may occur anywhere from the upper border of the duodenum or above it to the caudal border of the pylorus

Atypical origins of the gastroduodenal are correlated with variations in the mode of branching of the celiac artery These will not be repeated here because they have already been considered In this series of 200 bodies the celiac hepatic which supplied the hepatic (and therefore in most instances the gastroduodenal directly or indirectly through its branches) came from a hepatolienogastric trunk in 89 per cent Variations comprised a celiac hepatic derived from modified trunks such as hepatolienal hepatolienomesenteric hepatolienal plus hepatogastric *All of this seems complicated but may be rendered very simple when one considers that typically the hepatic after giving off the gastroduodenal divides into a right a middle and a left hepatic the middle hepatic (for the quadrate lobe) being a branch of either the right or the left hepatic (Figs 52 50) When the hepatic divides into the gastroduodenal and the right hepatic, the celiac left hepatic falls out and is replaced by a left hepatic from the left gastric (Fig 48) Similarly, when the hepatic divides into the gastroduodenal and the left hepatic, the celiac right hepatic falls out and is replaced by a right hepatic from the superior mesenteric* (Fig 81) *Finally, when the hepatic divides into the gastroduodenal and the middle hepatic, both right and left hepatics are replaced from other sources* (Fig 55) *Occasionally the blood supply of the stomach is accomplished by two separate main trunks arising from the aorta—a left trunk which supplies the splenic the left gastric, the left hepatic and the dorsal pancreatic, and a right trunk which supplies the right hepatic the middle hepatic the gastroduodenal and the right gastric* (Fig 66)

The statistical analyses of the 200 bodies dissected showed that gastroduodenal arose from a normal celiac common hepatic trunk in 75 per cent leaving 22 5 per cent for the replaced type of gastroduodenal coming from the left hepatic (11 per cent) the right hepatic (7 per cent) the middle hepatic (1 per cent) or the replaced hepatic trunk (3 5 per cent) and 2 5 per cent for gastroduodenals coming from other sources (celiac or superior mesenteric directly) (Figs 55 67)

Typically the gastroduodenal arose from a long common hepatic trunk before the latter divided into a right and a left hepatic branch (46 cases) (Fig 52) About half as frequently (27 cases) it arose at the same point or nearly at the same point along with the left hepatic and the right hepatic (Fig 69) It arose from the right hepatic after the left hepatic was given off in 3 5 per cent and from the left hepatic after the origin of the right hepatic in 1 per cent In 22

cases (11 per cent) it took origin from a celiacal left hepatic when the right hepatic was replaced from the superior mesenteric (Fig 84) in 14 cases (7 per cent) it came from the celiacal right hepatic when the left hepatic was replaced from the *left gastric* (Fig 57) *In* 2 cases (1 per cent) it took origin from a celiacal middle hepatic when both right and left hepatics were replaced from other sources in 3 cases (1 5 per cent) it sprang directly from the celiac artery these cases having replaced right and left hepatics or a replaced hepatic trunk (Fig 55) A direct origin of the gastroduodenal *from the superior mesenteric* was noted in 2 cases (1 per cent) in both of which it looped around the common bile duct to reach the anterior surface of the pancreas (Fig 16) Such looping of the gastroduodenal around the common bile duct could conceivably be the direct cause of intermittent jaundice as possible likewise with a subsidiary arcade of the retroduodenal artery (Fig 55)

The more constantly observed branches of the gastroduodenal comprise (1) the retroduodenal which in 90 per cent constituted its first branch Given off above the duodenum it coursed behind it supplying each of its four segments (2 and 3) the superior pancreaticoduodenal and the right gastro epiploic the usual terminal divisions of the gastroduodenal (4) the pyloric artery a branch of the distal end of the gastroduodenal or from the proximal end of the superior pancreaticoduodenal or the right gastro epiploic and emerging, as a rule from the caudal border of the pylorus (Figs 68 70 74 76 79 89)

The inconstantly observed branches of *the gastroduodenal artery* (frequently in communication with other regional arteries) comprise (1) the right gastric which commonly arose from it (8 per cent) (2) the supraduodenal artery of *Wilkie which likewise* frequently arose from it (25 per cent) and in addition to supplying the first part of the duodenum often sent twigs to the pylorus and communicated with the right gastric and the retroduodenal (3) the transverse pancreatic which instead of arising from the splenic via the *dorsal pancreatic arose from the gastroduodenal* the superior pancreaticoduodenal or the right gastro epiploic (10 per cent) (4) the cystic artery either its superficial branch (which became distributed to the peritoneal surface of the gallbladder the deep cystic branch arising in Calot s triangle) or the entire cystic (4 per cent) (Figs 46 40) (5) *the middle hepatic when the right and* the left hepatics were replaced from the superior mesenteric and the left gastric (2 cases) (Fig 55) (6) an accessory right hepatic which occasionally ascended to the fissured area under the gallbladder the area representing a lateral extension of the porta hepatis (Fig 91) (7) the middle colic which arose *from the* gastroduodenal or the right gastro epiploic (2 cases) and was anastomosed with the right gastro epiploic or the superior pancreaticoduodenal (Fig 51) (8) communicating branches Most of the latter arose *from the left* side of the gastroduodenal coursed on the anterior surface of the pancreas gave branches to the latter and occasionally to the pyloric transition zone and ultimately sank into the substance of the pancreas to communicate distally with the splenic or with its dorsal pancreatic branch (Fig 52) A posterior branch of the retroduodenal quite frequently swung back of the common bile duct to anastomose with the dorsal pancreatic (Fig 63)

Extremely complicated are instances *in which the* gastroduodenal or its terminal branches become associated with the superior mesenteric either directly or indirectly In one case the gastroduodenal arose from the common he*patic which after its origin from the* superior mesenteric passed throu h the

head of the pancreas coursed upward under the duodenum and thus simulated the gastroduodenal while the latter came off early was extremely short and hidden (Fig 38) In two instances the superior pancreaticoduodenal and the right gastro-epiploic along with the middle colic arose from the superior mesenteric in a common trunk while the gastroduodenal became dissolved into the retroduodenal and a branch which communicated with the right gastro epiploic (Fig 51) In an odd henomesenteric trunk the splenic arose from the left side of the superior mesenteric the gastroduodenal from its right side at the same level (Fig 67) The gastroduodenal in this case before dividing into its terminal divisions gave rise to the middle hepatic and the right gastric via a common stem and to a branch which passed behind the common bile duct to anastomose with the retroduodenal derived from the right gastric Just as a replaced right hepatic derived from the superior mesenteric may give rise to the middle colic so a right gastro-epiploic arising from the superior mesenteric may give off the middle colic (Fig 51) When the entire hepatic trunk arises from the superior mesenteric the gastroduodenal may be entirely dissociated from it and take origin from the celiac along with the splenic and the left gastric (Fig 19) An anastomotic branch connecting the middle colic with the dorsal pancreatic is common (Fig 29) In fact a dorsal pancreatic of celiac origin may serve as the main middle colic trunk after it has supplied the dorsum of the pancreas and emerged from its inferior border (Fig 40) An anastomosing vessel between the middle colic and the right gastro epiploic or the superior pancreaticoduodenal may be very large (Fig 59) Extremely interesting was the case in which the gastroduodenal after its origin from the superior mesenteric swung around the common bile duct from back to front but before doing so gave off the superficial cystic (Fig 16) A direct origin of the cystic from the superior mesenteric was never observed in this study the case just cited being the closest approach made The gastroduodenal may begin as a single vessel but upon approaching the duodenum become resolved into an extensive intricate anastomosing network of vessels from which emerge not only the superior pancreaticoduodenal and the right gastro epiploic but also the right gastric the supraduodenal and the retroduodenal arteries (Fig 51) Cases comparable with those cited are unquestionably the basis for the statement found in the literature that at times the gastroduodenal is missing It is not missing but is simply of different origin and pattern and of different import

Retroduodenal The cumbersome and confusing term the posterior superior pancreaticoduodenal was applied to this unlisted artery by Belou (1915) Petren (1929) Pierson (1943) and Woodburne and Olsen (1951) to distinguish it from the superior pancreaticoduodenal anterior in position and well known to the surgeon In the 200 bodies investigated the retroduodenal was present in all cases (99 per cent) except two where the artery was replaced by a branch from the dorsal pancreatic (Fig 81)

The term retroduodenal is the appropriate one for in 10 per cent (20 cases) it did not arise from the gastroduodenal and thus differed considerably from the superior pancreaticoduodenal which nearly invariably arises as one of the end branches of the gastroduodenal

There is great danger that *a confused and different terminology may again prevent the proper recognition of this surgically important retroduodenal artery as has been the case for nearly two centuries* Double pancreaticoduodenal arcades i e one anterior the other posterior to the head of the pancreas and the back of the duodenum made by dif

ferent arteries were first described by Haller in his Latin text in 1742 Varied and inaccurate description of the artery supplying the back of the duodenum by Verneuil in 1851 and by Wiart in 1899 and by others led to its omission from texts until it was conspicuously resuscitated by Belou in 1915 and by Petren in 1929 only to be forgotten again because of the cumbersome terms given to the artery—to wit the pancreatico duodenal postero superior (Belou) the posterior superior pancreaticoduodenal (Petren) Lest omission again be made the author deems it best to designate the artery forming the posterior pancreaticoduodenal arcade as *the retroduodenal, for the artery is distributed mainly to the back of the duodenum* It courses behind the first part of the duodenum and its branches are distributed to the back portions of the four segments of the duodenum relatively few fine twigs going to the pancreas

As estimated statistically in 200 bodies the retroduodenal artery came from the gastroduodenal in 90 per cent In the remaining cases (10 per cent) it came from the hepatic (4 per cent) the right hepatic (2 per cent) the aberrant right hepatic derived from the superior mesenteric (3 per cent) or was absent (1 per cent) the artery being replaced by a branch from the dorsal pancreatic (Fig 81)

As previously stated the retroduodenal arises from the gastroduodenal as its characteristic first branch in 90 per cent of the cases Its point of origin from the latter is high and lies above (occasionally behind) the duodenum and the head of the pancreas In its tortuous course the retroduodenal descends for several centimeters along the left side of the common bile duct crosses its supraduodenal portion anteriorly (in some instances posteriorly) and again descends for a centimeter or more along the right side of the common bile duct In the three respective positions it gives ascending twigs to the common duct (Figs 45 52 59) Its first branches are small, being distributed separately or via the supraduodenal to the first part of the duodenum (Figs 82 91 95 98) At about the middle of the posterior surface of the head of the pancreas behind the intrapancreatic portion of the common bile duct the retroduodenal forms the U shaped posterior pancreaticoduodenal arcade branches of which usually supply the posterior surfaces of all four portions of the duodenum and to a lesser extent the head of the pancreas *End branches of the artery frequently supply the first portion of the jejunum, a very important point to be considered in resection of the jejunum lest the first portion of the jejunum be deprived of its blood supply* (Figs 72 81 90 93)

The posterior pancreaticoduodenal arcade made by the retroduodenal is comparable with the anterior pancreaticoduodenal arcade formed by the well known superior pancreaticoduodenal but is more cranial in position The arcades unite with the superior mesenteric via a common inferior pancreaticoduodenal (60 per cent) or each arcade has its own inferior pancreaticoduodenal that of the posterior arcade arising frequently from the right side of the superior mesenteric at a higher level (Fig 50) Often the common inferior pancreaticoduodenal or the anterior or the posterior inferior pancreaticoduodenal arises from *the first or the second jejunal branch, or from the left side of the superior mesenteric,* the respective artery passing behind the latter—a fact to be remembered in gastrojejunostomies (Figs 72 90) Since both types of inferior pancreaticoduodenal arteries at sites of their origin from the superior mesenteric lie behind the head of the pancreas or the uncinate process the anterior must pass through the substance of the lower half of the head of the pancreas to establish its anastomosis

with the superior pancreaticoduodenal for in its initial course the latter is superficial in position

Supraduodenal It was thus designated by Wilkie because in his 10 specimens it arose from an artery located above the duodenum and became distributed to the upper anterior and posterior surfaces of the first part of the duodenum for an inch or more the area corresponding to the anemic spot which appears when this part of the duodenum is placed under tension (William Mayo) While concerned primarily with the blood supply of the upper border and the anterior surface of the first part (1 inch) of the duodenum one or more of its branches frequently reach the pylorus thereby involving the artery in the blood supply of the stomach (Fig 51)

The supraduodenal is markedly varied not only in its origin but likewise in its length size range of distribution and mode of anastomoses In this series of 200 bodies it was not determined or determinable as a specific branch in 6 per cent of the cases Most commonly it arose as a direct branch of the retroduodenal (50 per cent) or from the gastroduodenal (25 per cent) In the remaining cases comprising 19 per cent it arose from the right gastric (7 5 per cent) (Fig 19) the hepatic (5 per cent) including three replaced hepatic trunks (Figs 31 35 53) the right hepatic (5 per cent) including two of the replaced type (Figs 25 33 51 66) the left hepatic (1 per cent) and in one case from the middle hepatic (Fig 10) *

The supraduodenal is definitely not an end artery as claimed by Wilkie for frequently it communicated with branches from the gastroduodenal the superior pancreaticoduodenal the right gastric and the retroduodenal (Figs 51 59) and via branches of the dorsal pancreatic with the hepatic and the splenic (Figs 56 75 91 93)

Transverse Pancreatic and Dorsal Pancreatic Typically and in most cases (78 per cent) the transverse pancreatic arises as the major left branch of the dorsal pancreatic Origin of the dorsal pancreatic (1 to 4 mm in width) in 200 specimens was found to be as follows first part of the splenic (39 per cent) the hepatic or the right hepatic (19 per cent) the celiac (22 per cent) the superior mesenteric (14 per cent) the middle or the left colic (4 per cent) the gastroduodenal or the right gastroduodenal (2 per cent) Of the two right branches of the dorsal pancreatic one passes behind the portal vein to supply the uncinate process the other usually smaller emerges to the anterior surface of the head of the pancreas where it forms a prepancreatic arcade by anastomosing with the gastroduodenal or with one of its terminal divisions (Fig 66) In the neighborhood of its anastomosis the right branch of the dorsal pancreatic gives off a variable number of ascending twigs to the inferior border of the pylorus and the first part of the duodenum

In 10 per cent of the 200 cases the anastomotic right branch of the dorsal pancreatic was of such a large size (1 to 2 mm) as to constitute the transverse pancreatic artery which then variously arose as a separate trunk from the right gastro epiploic (6 per cent) the gastroduodenal (3 per cent) or the superior pancreaticoduodenal (1 per cent) (Figs 84 72 76) Arising from the listed vessels at the level of the duodenum the transverse pancreatic coursed along the inferior surface of the pancreas (at times for 9 cm) at the tail end of which it anastomosed with the a pancreatica magna from the left gastro epiploic or the splenic terminals Along its course

* In the 10 cases studied by Wilkie (1911) the supraduodenal had the following origin gastroduodenal (22 times) right hepatic 7 left hepatic 5 hepatic trunk 2 branch of the right gastric 1 branch of the cystic 1 In 2 cases it was double one arising from the hepatic the other from the left hepatic or gastroduodenal Since in the majority of cases the supraduodenal had no connection with the other gastric or duodenal arteries Wilkie regarded it as an end artery

it gave off several (2 to 5) slender twigs to the transverse mesocolon, affording that structure with an added blood supply (Figs 45, 57). At its commencement it sent a variable number of twigs to the lower border of the first part of the duodenum and to the pyloric end of the stomach, where they anastomosed with branches of other regional arteries. In some instances the origin of the transverse pancreatic was shifted to the superior mesenteric or to an accessory right hepatic from the superior mesenteric (Figs 57, 86). In one body the transverse pancreatic arising from the superior mesenteric was of such large size (5 mm) as to constitute an a. splenica secunda, the blood reaching the spleen through the a. caudae pancreatis, a branch of the splenic (Fig 121).

Superior Pancreaticoduodenal. This artery is the smaller terminal division of the gastroduodenal and arises from it as the latter vessel passes behind the first part of the duodenum. At its commencement it gives off several twigs to the transition zone between the pylorus and the duodenum, often furnishing a large pyloric branch (Fig 76). For a variably short distance the artery is superficial. It courses down behind the peritoneum in the anterior shallow groove between the descending portion of the duodenum and the pancreas, then sinks into the latter to anastomose behind the head of the pancreas with the inferior pancreaticoduodenal, a branch of the superior mesenteric. The arcade thus formed is the anterior pancreaticoduodenal arcade, in contrast with the textually unlisted posterior pancreaticoduodenal arcade formed by the retroduodenal artery (Fig 96).

In over half of the cases of this study (60 per cent) the two pancreaticoduodenal arcades (anterior and posterior) united with each other before joining the superior mesenteric via a common inferior pancreaticoduodenal (Fig 49). Next in frequency were cases in which each arcade had its own inferior pancreaticoduodenal, either from the superior mesenteric or from a jejunal branch (Figs 89, 72). From 1 to 7 duodenal and a varying number of pancreatic branches were given off by the superior and the inferior pancreaticoduodenals anteriorly and by the retroduodenal artery posteriorly. The inferior pancreaticoduodenal in addition gave off from 1 to 3 jejunal branches which coursed to the left and under the superior mesenteric artery (Fig 79).

In virtue of the arrangement of dual pancreaticoduodenal arcades, the duodenum is the only section of the intestine which has a double arterial arcade, one anterior, the other posterior in position. From both arcades a variable number of twigs are given off to the pyloric end of the stomach. The arcades may be double, triple, complete or incomplete. When two superior pancreaticoduodenals were present, the more medial one, after a short course on the superficial surface of the pancreas, sank into it to unite with the uncinate branch of the dorsal pancreatic. In other instances it joined with the common inferior pancreaticoduodenal, the right gastroepiploic or the transverse pancreatic. On several occasions the superior pancreaticoduodenal was anastomosed with the middle colic or an accessory middle colic (Fig 51). Most striking are instances in which a superior pancreaticoduodenal of hepatic origin (through a gastroduodenal from the latter), instead of joining the superior mesenteric, directly ascends behind the head of the pancreas to anastomose with a replaced right hepatic from the superior mesenteric, thereby establishing a collateral circulation between the celiac and the superior mesenteric and modifying the circulation of the liver, the stomach, the duodenum and the pancreas (Figs 84, 88).

Right Gastro-epiploic Invariably this artery is much larger than the left gastro epiploic which often is small or is represented by several vessels emerging from the terminal part of the splenic The distal end of the right gastro epiploic in many instances passes far beyond the midline of the lower border of the stomach Shortly after its origin it usually gives off the large ascending pyloric branch which becomes subdivided into 3 to 4 branches in its ultimate distribution some of the terminal twigs reaching the lower border of the first part of the duodenum (Figs 69 72) When the right gastro epiploic arises from the superior mesenteric as it occasionally does the superior pancreaticoduodenal may stem directly from the hepatic via the gastroduodenal (Fig 31)

The right gastro epiploic passes from right to left along the greater curvature of the stomach between the anterior two layers of the great omentum or between the gastrocolic ligament when fusion of the primitive omental layers (mesogastrium) with the transverse mesocolon has taken place Excessive clamping of the right gastro epiploic may cause severe injury to the superior mesenteric or its branches for the latter artery lies just behind it viz in the transverse mesocolon

Abutting the stomach closely or at a variable distance from it the right gastro epiploic in most cases of this study anastomosed boldly with the left gastro epiploic branch of the splenic (Fig 61) However this anastomosis very frequently (10 per cent) did not take place due to the fact that the left gastro epiploic was extremely small having previously become subdivided into a variable number of branches the terminals being less than 1 mm in width and having passed into the stomach substance before a visible anastomosis could be verified (Fig 57) Accordingly in every instance of surgical interference the existent vascularization along the greater curvature should be inspected lest in the absence of an anastomosis an area of ischemic necrosis of the stomach be established by the short cutting of either artery An assumed anastomosis between the right and the left gastro epiploics may prove postoperatively to be very disconcerting in unexpected devitalization of a gastric area with subsequent gangrene

From the upper (subgastric) omental arc formed by the right and the left gastro epiploics or in its absence from the right and the left gastro epiploic arteries respectively considered are given off ascending gastric branches and descending omental or anterior epiploic branches The ascending gastric branches anastomose with descending gastric branches of the right and the left gastric found along the lesser curvature The omental or the anterior epiploic branches short or long descend between the two anterior layers of the great omentum The short omental branches descend for a variable distance to anastomose with neighboring omental branches and are well illustrated in texts of anatomy (Figs 1 2)

Of the long omental or long anterior epiploic branches nothing is recorded or illustrated as to their ultimate distribution in standard texts of anatomy or surgery And yet as far as collateral blood supply to the stomach is concerned they are very important for through the left gastro epiploic and the short gastrics with which they ultimately communicate they may bring blood to the stomach The long omental branches proceed to the free edge of the great omentum (pars libera omenti) where they turn upward to become the posterior epiploic arteries (rr epiploici posteriores) Many of these join the large epiploic arch (arcus epiploicus magnus of Barkow) situated in the posterior

layer of the great omentum distal to the transverse colon (Fig 1) The arch is usually formed by the right epiploic from the right gastro epiploic and by the left epiploic from the left gastro epiploic In some instances in this study the right limb of the arc arose from the transverse pancreatic or from the second large epiploic branch of the right gastro epiploic (Fig 100) From the arc of Barkow ascend slender arteries that anastomose with similar slender branches given off from the middle and the left colic and from the transverse pancreatic artery Both the ascending and the de scending posterior epiploic arteries course between the posterior layers of the great omentum Their ultimate and penultimate branches anastomose with the vasa recta of the middle colic but apparently are not of sufficient caliber *to take over the blood supply once the* middle colic has been rendered func tionless

The most striking aberrancies of the right gastro epiploic noted in this work comprised (1) origin from the superior mesenteric separately (1 5 per cent) or *with the middle colic and the superior* pancreaticoduodenal (1 per cent Figs 2 51) (2) anastomosis with the mid dle colic via a vessel as large as the latter (1 per cent Fig 59) (3) origin from a gastroduodenal derived from the superior mesenteric (2 cases Figs 46 67) (4) *origin from the superior mesen* teric via the common inferior pancre aticoduodenal (1 case Fig 97)

Left Gastro-epiploic In origin size length constituent branches number and mode of vascular connections with the stomach the spleen and the pan *creas* the left gastro epiploic is such a markedly varied artery that a uniform concept of it cannot be formed Surgi cally considered, therefore every case bears inspection as to the character of the artery before it is ligated In about three fourths of the cases (72 per cent) it arises from the splenic trunk several *centimeters (1 to 4) proximal to the* latter s division into its two or three terminal branches (Fig 60) Next in frequency (22 per cent) is its origin from the inferior splenic terminal or from one of the latter s lienal branches (Fig 61) Least frequent is its origin from the middle of the splenic trunk (6 to 7 cm from the spleen Fig 129) or from a superior terminal The artery may be replaced by 2 to 3 vessels the main vessel arising from the splenic ar tery or its branches the other or others usually smaller, from a polar artery given off by the splenic to the spleen In a few instances in this study the left gastro epiploic took origin from the in terior of the spleen a fact to be remem bered in splenectomies for the artery may be coiled and superimposed on the *splenic terminal branches*

The left gastro epiploic reaches the stomach below the fundus by means of the phrenicopancreaticolienal ligament and descends along the left side of the greater curvature in the anterior layer of the great omentum which extended to the spleen becomes the *gastrolienal* ligament At times adjacent at times far removed (20 mm) from the inferior border of the stomach the left gastro epiploic in most instances (90 per cent) effects a direct anastomosis with the right gastro epiploic constituting the arcus arteriosus ventriculi inferior of Hyrtl (Fig 61) As previously stated it is important to know that *in many in stances (10 per cent) the left gastro epiploic does not anastomose with the right gastro epiploic at all,* while in other cases anastomosis is very meager (Fig 60) *When no large anastomosis is* present the left gastro epiploic often be comes resolved into numerous small branches which unite with similar branches from the right gastro epiploic which prevailingly, is larger since it

supplies a larger section of the greater curvature (Fig 95)

Branches of the left gastro epiploic comprise (1) fine and stout fundic branches (2 to 4) (2) a variable number of short ascending gastric branches to the anterior and the posterior surfaces of the stomach (3) short and long descending or omental branches some of which communicate with like branches from the right gastro epiploic and with branches from the left colic (4) pancreatic rami to the tail of the pancreas one of these is usually large and is known as the a caudae pancreatis the others (2 to 3) are small (5) inferior polar arteries to the spleen which vary in number (1 to 5) size and length (3 to 8 cm) and in some instances furnish the blood supply to an accessory spleen located in the pancreaticolienal or the splenocolic ligament (Fig 129)

The left gastro epiploic may arise from an inferior polar the caliber of which is larger than the left gastro epiploic itself The same may be said of its occasional origin from a branch of the inferior splenic terminal As it approaches the spleen the left gastro epiploic may give rise to an irregular contoured arch from which many small lienal branches arise these in turn giving off short gastrics Collectively considered the blood volume coming to the spleen through the inferior splenic polar branches (2 to 4) of the left gastro epiploic may approach that reaching the spleen through its primary terminal lienal branches (Fig 54) The main splenic blood route in such cases is through the left gastro epiploic just as in certain instances a main route may be through an enlarged transverse pancreatic arising from the superior mesenteric (Fig 121)

Like its parent trunk the left gastro epiploic is frequently tortuous and looped but rarely coiled Its relation to the tail of the pancreas varies in accordance with its site and mode of origin from the splenic and with the volumetric proportions of the pancreas the artery frequently coursing in the pancreaticolienal ligament between the tail of the pancreas and the spleen Tortuosity may extend to the inferior polars given off by the left gastro epiploic the latter and its branches lying in loops and spirals on the gastric surface of the spleen making the identification of the left gastro epiploic somewhat disconcerting and difficult In such instances the exact origin of the short gastrics cannot be ascertained without extensive dissection and repeated manipulation

An important branch of the left gastro epiploic is the left epiploic artery (a epiploica sinistra) which forms the left limb of the arcus epiploicus magnus of Barkow the right limb being formed by the right epiploic (a epiploica dextra) from the right gastro epiploic or the transverse pancreatic (Fig 100) The arc is usually found in the posterior layer of the great omentum below the transverse colon which it supplies by ascending rami (posterior epiploics) albeit the latter are of small caliber (Fig 1) The arcade of Barkow may be double and on occasions is situated in the anterior layer of the great omentum In incisions of the splenocolic and the phrenicocolic ligaments one of the large epiploic arteries (at times the main left epiploic) may be severed affording the reason for resultant massive hemorrhage

Short Gastrics or Vasa Brevia These vary in number (4 to 10) size site of origin and mode of distribution some of them reaching the esophagus Collectively considered *they comprise an upper a middle and a lower group* the latter being the longest The shorter ones arise from the splenic trunk from the superior splenic terminal or its branches or from a superior polar the longer ones arise from the inferior splenic terminal and from the left gastro-

epiploic or its branches In some instances one or two may arise from the interior of the spleen unaccompanied by a vein Leaving the phrenicolienal ligament the short gastrics pass into the gastrolienal ligament to reach the fundus and the cardio esophageal end of the stomach where they ramify over the anterior and the posterior surfaces and anastomose with branches given off by the left gastric the left gastro epiploic and the left inferior phrenic When an aberrant left hepatic stems from the left gastric or an accessory left gastric stems from the left hepatic the cardio esophageal branches of the respective vessels communicate with the short gastrics which have reached the esophageal region (Figs 48 63) For further description of the short gastrics the reader is referred to the splenic artery

Blood Supply of the Entire Esophagus

Standard textbook descriptions of the blood supply to the esophagus are not only varied and inaccurate but also extremely inadequate as compared with present surgical needs A generation ago the esophagus was regarded as operatively inaccessible but ever since the first successful transthoracic esophagectomy was performed by Max Thorek of Chicago (1913) operative procedures on the esophagus for malignancy atresia diverticula etc have become more diverse more widespread and more difficult as extensively illustrated in the review on esophagitis (with 193 references) recently published by Craighead of New Orleans (1954) When it is realized that of those who bleed from esophageal varices 20 per cent will die with their first hemorrhage (Witter and First 1953) every surgeon should know the blood supply of this important section of the digestive tract Furthermore according to Patek one third of all patients with portal cirrhosis under medical treatment have hematemesis and of these only 50 per cent will be alive after the first year

Viability of the esophagus, as that of any other enteric segment, depends on the maintenance of an adequate blood supply Detailed anatomic knowledge regarding esophageal arteries has been made available by the investigations of Shapiro and Robillard (1950) and by those of Swigart Siekert Hambley and Anson After a short summary of these two recent contributions has been given the author will present his own observations on the blood supply of the abdominal esophagus

Shapiro and Robillard studied the blood supply to the esophagus in 50 bodies during necropsy They maintain that the esophageal circulation is a shared vasculature Accordingly during surgical mobilization in separating the esophagus from embryologically related structures as the trachea the bronchi and the diaphragm extreme care should be taken lest the freed segment become devascularized Unlike the patterns in the small and the large intestines the esophageal arteries course in longitudinal anastomotic chains rather than in a radial direction

The primary supply to the pars cervicalis of the esophagus was found to be the inferior thyroid artery the right supplying more branches than the left Posterior esophageal vessels were relatively few and small The anterior arteries are functional tracheo esophageal vessels which course and bifurcate in the groove giving twiglike branches to both structures The major arteries of the pars cervicalis arose from the inferior thyroid (14 cases) the subclavian (12) the thyreoidea ima (3) the common carotid (1) Anastomoses and collaterals were established from the superior thyroid the bronchial the aortic twigs and with each other Accessory arteries comprised the subclavian (9 cases) the

aorta (4) the carotid (2) and the vertebral (1)

The pars bifurcalis of the esophagus (portion adjacent to the tracheal bifurcation) was supplied primarily by bronchial arteries from the aorta or the right third or fourth intercostal artery In three cases it received branches from the aorta and the arch In this region the left side of the esophagus prevailingly had a greater number of branches Branches from the right bronchial pass most frequently behind the esophagus Accessory arteries comprised branches from the aorta and the arch (23 cases) from the innominate (4) the subclavian (5) the carotid (2) the upper intercostal (6) and the internal mammary (7) Anastomoses and collaterals were variously established with the inferior thyroid the subclavian the carotid the third intercostal the aortic twigs and the thoracic esophageal Authors maintain that extensive mobilization of this part of the esophagus may readily lacerate both bronchial arteries and in some instances also the tracheo esophageal anastomotic arc between the bronchial and the inferior thyroid arteries

The pars thoracalis of the esophagus in most instances is supplied by only two arteries (upper and lower) and not by 3 to 4 as commonly taught Nearly invariably these two arteries are unpaired and arise from the anterior aspect of the aorta The upper or superior is small (3 to 4 cm) and arises at the level of T 6–7 interverterbal disk the lower or inferior is long (6 to 7 cm) and arises at T 7–8 disk level Both arteries pass behind the esophagus and divide into right and left trunks which give off ascending and descending branches Anastomoses comprised union with bronchial arteries the inferior phrenic and the left gastric Occasionally the section received branches from the lower intercostals the celiac artery and the aorta

Pars Abdominalis It received its primary blood supply from the left gastric via 2 to 4 esophageal branches Other major arteries which in some instances supplied the infradiaphragmatic segment comprised the left inferior phrenic (9 cases) the aorta (3) the accessory hepatic (9) the splenic (1) and the celiac (8) In about two thirds of the cases there was an appreciable thoracico abdominal anastomosis between the posterior abdominal esophageal branch and the inferior thoracic esophageal artery Anastomosis of the inferior phrenic comprised union with the inferior esophageal the gastric the splenic the hepatic the renal and the suprarenal arteries

In speaking of the pars abdominalis Shapiro and Robillard state that

if the left gastric artery is severed to facilitate gastric mobilization and the complete length of the esophagus is extensively freed the lower esophagus may be seriously devascularized In the writer s judgment the inferior phrenic artery may not always be relied upon since it contributes relatively little to the blood supply here and anastomoses between the bronchial and left gastric artery are rare (*Ann Surg* 131 171 1950)

Swigart Siekert Hambley and Anson of Northwestern University (1950) after a study of 150 bodies give the following report on esophageal arteries The cervical portion of the esophagus is supplied by the inferior thyroid artery The ascending and the descending portions of this artery in the majority of cases give rise to one esophageal branch occasionally to two The terminal branches give rise to esophageal vessels more frequently than the ascending or the descending part but collectively considered they are less numerous than those coming from the other two segments In many instances a tracheo esophageal artery arises from the ascending segment and courses downward in company with the

epiploic or its branches In some instances one or two may arise from the interior of the spleen unaccompanied by a vein Leaving the phrenicolienal ligament the short gastrics pass into the gastrolienal ligament to reach the fundus and the cardio esophageal end of the stomach where they ramify over the anterior and the posterior surfaces and anastomose with branches given off by the left gastric, the left gastro epiploic and the left inferior phrenic When an aberrant left hepatic stems from the left gastric or an accessory left gastric stems from the left hepatic the cardio esophageal branches of the respective vessels communicate with the short gastrics which have reached the esophageal region (Figs 48 63) For further description of the short gastrics the reader is referred to the splenic artery

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The next most frequent source of esophageal arteries is *from the gastrohepatic arterial route*, of which there are three variants (1) the aberrant left hepatic from the left gastric (Fig 59) (2) the anastomotic arc between the left gastric and the left hepatic (Fig 53) (3) the accessory left gastric from the left hepatic (Fig 63) From an embryologic point of view, the three routes undoubtedly have the same fundamental origin in a primitive gastrohepatic circle which according to Piquand (1910) exists in the fetus between the left hepatic and the left gastric in the lesser omentum *When the upper half of the circle falls out and the lower half persists an aberrant left hepatic stemming from the left gastric will eventuate (25 per cent) and, vice versa when the process of involution is the reverse the persistent upper half becomes an accessory left gastric stemming from the left hepatic* (Fig 65) *In the third type the primitive gastrohepatic arterial circle persists*[3]

Aberrant Left Hepatic *In fully one fourth of the population* the left gastric gives off a large left hepatic artery (3 to 5 mm in width) Of the 16 cases having an aberrant left hepatic from the left gastric in the 200 specimens studied *one half were replaced left hepatics one half were accessory* Invariably an aberrant left hepatic as it proceeded to the liver along the peripheral edge of the lesser omentum gave off 1 to 3 esophageal branches similar to those arising directly from the left gastric (Fig 59) In many instances the esophageal supply from an aberrant hepatic was accomplished by one or two large cardioesophageal vessels which not only supplied the esophagus but also became distributed over the fundic region of the stomach in an arterial network which was anastomosed with the short gastrics of splenic origin and with branches from the left inferior phrenic (Fig 48)

Anastomotic Arc In many bodies the primitive gastrohepatic arterial circle of Piquand (1910) persists i e the connection between the left gastric and the left hepatic is retained (Fig 53) This anastomosing artery varies from 0 5 to 2 mm in width and accordingly affords an appreciable supplementary blood supply to the liver It may unite with the left hepatic directly or with its lower branch (Fig 49) In some instances it joins the left hepatic after the latter has entered the liver In its upward course it gives off from 1 to 4 esophageal branches and a variable number of twigs (1 to 6) to the liver in the umbilical fossa region Occasionally it takes origin from the terminal part of the cardioesophageal branches of the left gastric and in rare instances gives rise to the left inferior phrenic (Figs 72 79)

Accessory Left Gastric. While an accessory left hepatic from the left gastric occurs frequently (11 5 per cent) the incidences of the left hepatic giving rise to a large accessory right gastric are rare since most of the accessory left gastrics stem from the aorta the celiac or the splenic as previously noted The accessory left gastric given off by the left hepatic is usually a large vessel (2 to 3 mm) supplying not only the esophagus with 1 to 4 twigs but also a relatively large area of the fundic region of the stomach where it communicates with the short gastrics of splenic origin (Figs 63 65)

Surgically considered it may be a matter of *life or death* to distinguish between the artery coming from the left gastric to the liver and the artery coming from the left hepatic to the stomach

[3] Comparable observations were made by Adachi (1928) He found an accessory artery in the lesser omentum 75 times in 252 bodies (29 8 per cent) 1 were accessory left hepatics 30 of these being the only left hepatic present 28 were accessory left gastrics and 2 were intermediate forms

recurrent laryngeal nerve To prevent sloughing at the proximal end of the esophagus in esophagogastric resections, the authors reiterate the warning of Sweet (1946) that the esophageal branches of the inferior thyroid should be preserved

The thoracic portion of the esophagus is supplied most commonly by branches from the left inferior bronchial artery which descends and anastomoses with the proximal (first) esophageal artery stemming from the aorta Next in frequency are esophageal branches from the superior right bronchial artery that ascend and anastomose with a branch of the cervical group

Patterns of the bronchial arteries comprised 8 types of which the following were the most common (86 per cent) Type I 2 left 1 right bronchial (18 per cent) II 1 left 1 right (24 per cent) III 2 left 2 right (14 per cent) Esophageal arteries may arise from the superior left bronchial as well as from a second right bronchial *The segment of the thoracic esophagus just below the lower right bronchus has the least blood supply*

Esophageal arteries arising directly from the aorta vary from 0 to 2 and not 4 to 5 as stated in the texts The site of their origin is predominantly at the level of the seventh and the ninth ribs In one fifth of the specimens the right intercostal arteries were the source of origin of esophageal branches the fifth right intercostal serving as the stem more frequently than any other intercostal Exceptionally on the right side esophageal arteries arose from the internal mammary the costocervical trunk and the subclavian artery

The abdominal esophagus was supplied by the left gastric 2 to 3 esophageal branches arising from this vessel in over three fourths of the specimens Accessory left hepatics furnished esophageal branches in 10 per cent and in over one half of the cases the left inferior phrenic gave off an esophageal branch

Blood Supply of the Abdominal Esophagus (200 Dissections)

In virtue of its attachments to the diaphragm by the phrenico esophageal ligament the abdominal portion of the esophagus becomes vascularized primarily by vessels coursing in the lesser omentum and by those supplying the left side of the diaphragm through which the esophagus passes The former vessels comprise the left gastric the aberrant left hepatics (accessory or replaced) arising from the left gastric the accessory left gastric supplied by the normal left hepatic or celiac a cardio-esophageal branch arising separately from the celiac the aorta or the splenic. Vessels of the second group are branches of the left inferior phrenic the diverse origin of which will be discussed later In many instances some of the short gastrics reach the esophageal region and afford an additional blood supply from the splenic (Figs 97 99 100)

In practically all of the 200 specimens studied the left gastric gave off from 1 to 4 esophageal branches which upon reaching the esophagus coursed in a direction parallel with its longitudinal axis and became distributed to the anterior surface and to a lesser degree to the posterior surface of the right side of the viscus While the mode and the site of origin of the esophageal arteries from the left gastric showed considerable variations two main patterns prevailed to wit (1) the esophageal arteries arose from a large common cardio esophageal branch given off by the left gastric shortly before it turned caudally along the lesser curvature (Fig 88) (2) the esophageal branches were given off separately and in seriation from the ascending arched portion of the left gastric (Figs 77 78)

placed left hepatic derived from the left gastric with those arising from an accessory left gastric derived from the left hepatic the celiac the aorta or the splenic In some instances two left inferior phrenics are present one of left gastric origin supplying the anterior surface the other of aortic origin supplying the posterior surface of the esophagus (Figs 71 79)

The site and the mode of origin of the inferior phrenics are markedly varied In the 200 specimens studied the following main types of origin were encountered (1) both from the aorta separately or via a common stem (2) both from the celiac separately or via a common trunk (3) one from the aorta the other from the celiac (4) the right from the renal artery or the renal polar the left from the aorta or the celiac (5) the left from the left gastric the right from the aorta or the celiac (6) the left from an aberrant left hepatic stemming from the left gastric the right from the celiac or the aorta

Statistically estimated the inferior phrenics in most cases had an independent origin from the celiac (Fig 27) the left arising more frequently (12 per cent) from the celiac than the right (32 per cent) The inferior phrenics arose separately from the aorta (Fig 50) this being more frequent on the right side (12 per cent) than on the left (8 per cent) In about 40 per cent of the cases the right and the left inferior phrenics arose from a common trunk emanating from either the aorta (20 per cent) the celiac (18 per cent) or the left gastric (2 per cent) (Figs 62 98 71) An independent i e bilateral origin of the inferior phrenics was accordingly the most common (60 per cent) (Figs 48 49 50 60 74 78)

Infrequent sites of origin of the inferior phrenics comprised the renal arteries for both for right or for left (Figs 68 83) the renal polar artery for right or left (Fig 18) the left gastric for left or both (Fig 71) an accessory left gastric from the left hepatic (Fig 79) the splenic for left (Fig 135) an aberrant left hepatic from the left gastric for left (Fig 79) an aberrant right hepatic from the superior mesenteric for right

The cited percentages are comparable with those reported by Greig Anson and Coleman (1951) Distinguishing 22 different patterns they found that in 92 per cent (125 bodies) the phrenic arteries arose from the aorta or the celiac axis either independently or by a common trunk with the vessels of the opposite side A bilateral origin of them was noted in 66 per cent In 2 6 per cent they came from the left gastric and in 1 case the right phrenic arose with the internal spermatic artery via a common trunk Of the 42 arteries arising from the renals 38 were encountered on the right the greater frequency on the right being due to the fact that in its upper abdominal portion the aorta lies to the left of the midline

In the series studied by the author the inferior phrenics varied in size (1 to 4 mm) and occasionally were very tortuous for the greater part of their course simulating in this respect the internal spermatic artery Exceptionally they were paired on one side or on both In its ascent on the diaphragm the left inferior phrenic in some instances supplied branches to the capsule (Glisson s) of the liver (Fig 71) Not once in a study of over 500 bodies did the inferior phrenics give origin to a main right or left hepatic artery albeit Susloff in 1907 reported *a right hepatic having such origin from the right inferior phrenic*

Collateral Circulation of the Stomach

As is the case with the spleen the stomach presents two main types of collateral pathways viz those *within and* those without the system of the gastric vasculature The former are made up of

The former may be the only blood supply to the left lobe of the liver and when inadvertently lacerated or deliberately ligated may cause fatal ischemic *necrosis of the left lobe of the liver* as evidenced in postmortem examinations and recorded in the literature by Ritter (1922) who in the cases previously reported found *a mortality of 100 per cent after 10 days when the left hepatic was severed*

Cardio esophageal Branch This minute vessel constitutes one of the most frequent and independent types of accessory left gastric arteries Of small caliber often less than 0 5 mm it may take origin from the arched part of the left gastric from the celiac the aorta the first part of the splenic or the inferior phrenic (Figs 38 113 95 16) Coursing directly to the cardiac end of the stomach it supplies this region and the esophagus with a variable number of twigs the latter passing to both the anterior and the posterior surfaces In some instances it is threadlike and may be overlooked as a bleeder as is the case with the superior polar branch of the splenic (Fig 60)

Short Gastrics The esophageal blood supply coming from the short gastrics varies with the number and the caliber of the latter Short gastrics reaching the cardia are frequently prolonged on the abdominal esophagus where they anastomose with cardio esophageal branches derived from other sources notably with those from the left gastric and the left inferior phrenic (Figs 72 82)

Esophageal Branches from the Inferior Phrenic

The blood supply which the esophagus receives from the esophageal branches of the left inferior phrenic should never be overlooked albeit it cannot be relied upon for the sole blood supply to the infradiaphragmatic part of the viscus (Shapiro and Robillard 1950) Developmentally considered the inferior phrenics are usually regarded as visceral branches of the aorta rather than parietal they having been displaced caudally with the descent of the diaphragm As the esophagus passes through the diaphragm it comes in the vascular terrain supplied by the left inferior phrenic and accordingly receives a supplemental blood supply from it Typically the left inferior phrenic takes origin from the aorta or the celiac either independently or along with the right inferior phrenic by a common stem at the apex of the aortic hiatus After emerging from the latter it passes over the left crus of the diaphragm and ascends on the anterior aspect of the diaphragm behind the esophagus Reaching the dome it divides into a smaller *posterior branch which anastomoses* with the lower intercostals and into a larger anterior branch which unites with the pericardiophrenic artery at the periphery of the central tendon

In the majority of cases the left inferior phrenic after it has passed under the esophagus gives off a *recurrent branch* which breaks up into several branches (2 to 4) on the posterior surface of the esophagus (Fig 48) The ascending rami course through the hiatus to anastomose with *thoracic esophageal branches,* the descending rami anastomose with the short gastrics of splenic origin Quite frequently the recurrent esophageal branch of the inferior phrenic as it approaches the junction point of the esophagus with the stomach divides into a posterior esophageal branch and an anterior branch which becomes distributed to the fundic region of the stomach where it anastomoses with the short gastrics (Fig 71)

Additional anastomoses of the esophageal branch of the left inferior phrenic are those established with the cardio esophageal branches of the left gastric with the esophageal branches coming from an accessory or the re

Arteriovenous (AV) Anastomoses and Capillary Blood Flow

The problem of the existence of generalized communications between the blood vessels of the stomach via direct AV anastomoses as claimed by Barlow et al (1951 see page 18) is of fundamental surgical and clinical importance Excellent reviews on AV anastomoses were made by Clark of the University of Pennsylvania (*Physiol Rev* 18 229 1938) and by Clara (Die Arterio venosen Anastomosen Leipzig Barth 1939) Knisely with Saunders of the University of South Carolina (1954) published a comprehensive review (197 references) of microscopic studies that have been made on small blood vessels in living tissues (*Arch Pathol* 58 309 1954)

AV anastomoses were described by Muller (1844) Sucquet (1862) Hoyer (1877) Bourceret (1885) Gerard (1895) Grosser (1902) Herrick (1907) Schumacher (1908) Masson (1924) and Clara (1927) and in living tissue by Grant (1930) Grant and Bland (1931) Sir Thomas Lewis (1931) Modell (1933) Eliot Clark (1938) Prinzmetal et al (1948) Simkins et al (1948) Tobin and Zariquiey (1953) and Zweifach

Hoyer (1877) gave one of the first descriptions of AV anastomoses (ear nose nails sex organs) and because of their position in peripherally located organs regarded them as being associated with the warming of these parts when exposed to cold a viewpoint proved by Grant the first to study AV anastomoses in the ears of living rabbits (1930)

By means of a double walled transparent chamber inserted in the ears of rabbits Clark and Clark (1939) obtained a clear visualization of AV anastomoses and for many years studied them under many conditions Using Poiseuille s law Clark estimated that 256 times as much blood could pass through an AV anastomosis 40μ in diameter as through a capillary of 10μ Any AV channel could suddenly stop acting as a stopcock AV anastomoses have since been reported as being present in spleen lungs kidney liver stomach and heart

As regards a v capillaries (i e preferential channels) some investigators have seen them in living tissue (Zweifach) while others have not (Webb) Knisely a pupil of Bensley at the University of Chicago (1936) was the first to have shown the role a v capillaries play in the intermediate circulation of the spleen a work confirmed by Peck and Hoerr Palm (1951) and Nakata of the Osaka Medical College of Japan (1954) who found no evidence of terminal arterioles opening into reticular spaces

Subsequent studies by Knisely and coworkers on sludged blood (*Science* 106 431 1947) as seen in living tissue in traumatic shock in malaria infected monkeys and in patients with varied diseases showed that *the shape and the dimensions of small vessels constitute a perpetual bottleneck in their peripheral vascular system* Knisely s most recent paper (with Saunders 1954) is a report of the measurements made on arterioles in the mesentery before and after embolization as ascertained with a new type of ocular microscope which permits measurements of parts of living tissue untouched Further data on living capillaries are to be found in the works of Chambers and Zweifach (1948) and Williams (1954) The most recent and advanced accounts of microcirculatory physiology and pathology are published in *Anat Rec* 120 239 1954 Participants in the conference held for this purpose were Clark Webb and Nicoll Knisely Zweifach Lutz and Fulton Forbes Minard Osserman and Howell Harvey and Jow Loeser and Bloch For a purely histologic aspect of capillaries and the unmyogenic character of Rouget cells see the author s account thereof published in *Anat Rec* in 1936

gastric vessels the branches of which communicate in most instances with themselves the latter are effected by regional arteries the branches of which communicate with gastric and esophageal arteries The inside gastric routes are (1) arcus arteriosus ventriculi superior (2) arcus arteriosus ventriculi inferior (3) arcus epiploicus magnus of Barkow

The outside gastric collateral pathways are numerous and extremely diversified since they are dependent on the divisional patterns of the celiac artery and on the varied manner in which the main gastric arteries have an aberrant origin or may be supplemented by additive vessels The major outside routes comprise those likewise operative in the collateral circulation of the spleen—viz (1) circulus transpancreaticus longus (2) circulus pancreaticoduodenalis (3) circulus coronarius inferior (4) circulus gastrolienalis accessorius (5) circulus gastrolienophrenicus A description of the cited routes is given in Chapter 13

As regards the esophagus it will be recalled that Shapiro and Robillard stated that *when the left gastric is severed to facilitate gastric mobilization the lower esophagus may be seriously devascularized* since the supply from the left inferior phrenic is meager and anastomoses between the bronchial arteries and the left gastric are rare In contrast with the observations of these authors the present study of 200 specimens gave ample evidence of the *important role which the left inferior phrenic artery can play* in the collateral circulation of the spleen the stomach and the esophagus to wit in a pathway termed the *circulus gastrolienophrenicus* In most cases the esophageal branches of the left inferior phrenic showed communications with the short gastrics of splenic origin and with the cardio esophageal branches derived from the left gastric from an accessory left hepatic stemming from the left gastric or from an accessory left gastric given off by the left hepatic (Fig 100) On a few occasions the dorsal pancreatic artery arose from the left inferior phrenic thereby establishing a collateral pathway between this vessel and those of the pancreas via its transverse pancreatic branch (Fig 90) Through the latter a pathway could be routed back to the stomach and the esophagus through the a caudae pancreatis the inferior terminal branch of the splenic and the latter s short gastric branches

The anatomic admonition regarding the nonreliability of collateral pathways for the splenic and the pancreatic circulations applies equally well for the vasculature of the stomach and the esophagus For example the anastomoses between the right and the left gastro epiploics does not always take place it being minimal or absent in 10 per cent of the population (Fig 57) The splenic should be ligated distal to the origin of the left gastro epiploic lest the greater curvature be deprived of its blood supply and the tail of the pancreas suffer necrosis cyst formation or fistulization *as claimed by Henschen (1928)* The left gastric should always be studied with care before undertaking ligation *of it for in one fourth of the population a left hepatic arises from it, and, in instances the entire hepatic* (Fig 20) The *middle colic may stem from the gastro* duodenal Severance of the latter in such a case would induce gangrene in *the transverse colon* The gastroduodenal itself may arise from the superior mesenteric (Fig 67) *Before proceeding with the closure of the duodenal stump, it is but careful and thoughtful surgery to see and know that an adequate blood supply reaches the stump, for without it the suture lines may give way with disconcertingly fatal results*

blood or blood staining fluid in the abdomen should make the surgeon aware of this condition Omental torsion and the pathologic changes associated with it are discussed fully by Anton Jennings and Spiegel (1945) Unknown are the nature and the scope of the nerve supply to its blood vessels the omental nerves being few and the anatomic basis for the contraction and the dilation of its capillaries through capillary nerves and Rouget cells being largely problematical as shown by the author in a special attempt to solve this problem (1935 1936)

Striking and of unknown biologic (clinical) significance are the breakdown the isolation and the involution of numerous capillary omental tufts and the neoformation of lymphoid perivascular lymphoid follicles following x ray irradiation (R 600) as observed by the author in experiments on the omentum of rabbits (1933) Largely unknown are the routes and the modes of peritoneal absorption (Maclmull and Michels 1932) the great omentum most probably playing a definite role in mammals where it vastly increases the peritoneal surface Largely unknown is the role which the great omentum plays in lymphatic drainage (through stomata?) in the formation and the destruction of blood cells in the general defense mechanism of the abdominal cavity in shock absorption in fat metabolism and in the production of peritoneal exudate cells—the percentages of the latter especially mast cells varying considerably in different diseases

As a hematopoietic organ the profusely vascularized great omentum is highly active and productive as evidenced in particular in its production of lymphocytes (taches laiteuses or milk spots) and clasmatocytes (Ranvier) Few other tissues in the body in the form of whole mount preparations afford a comparably clear approach to the study of the developmental potencies of connective tissue cells capillaries and pericapillary cells fat cells eosinophils and mast cells (Michels 1938 in Downey s *Handbook of Hematology*, Section IV pp 232–372—160 references on mast cells)

Unknown finally is the cause for the selective and the seemingly purposeful migration of the great omentum to sites of injury and infection (e g gallbladder pelvic cavity) and to body orifices immediately previous to herniation of abdominal organs (e g inguinal and femoral hernias) The last cited phenomena definitely are related to intra abdominal pressure changes but the cause for the selective migration of the great omentum to sites of injury and infection is still a very obscure and enigmatic biologic phenomenon It may be connected with hemodynamic laws the force of the blood stream in the omental arteries effecting positional changes much as the force of water under sudden different pressure impulse changes the position of the garden hose

The mode of formation of the great omentum as a leftward directed bag like bulge of the primitive dorsal mesogastrium and the subsequent fusion of its posterior two layers to the transverse colon and the transverse mesocolon (Lockwood 1883) during the fourth month of intra uterine life has already been discussed In the adult the great omentum consists of two portions (1) a pars libera omenti which extends from the transverse colon downward to the omental s free distal end (2) a pars mesocolonis omenti which extends from the omental attachment of the transverse colon upward to the anterior inferior surface of the pancreas—i e the site of attachment of the transverse mesocolon with which the original posterior two layers of the great omentum become fused Actually then this section (i e the transverse mesocolon) represents the anterior layer of the posterior

Let knowledge grow from more to more
But more of reverence in us dwell
—TENNYSON

11

Blood Supply of the Great Omentum and the Transverse Mesocolon

Biologic Significance and Morphology of the Great Omentum

The blood supply of the great omentum is rarely dealt with in detail most textbooks devoting but a few lines to its vascularization The omission is not only regrettable but also anatomically considered inexcusable That the omental blood vessels are of fundamental importance is obvious from the fact that in operative procedures on the upper abdominal organs the great omentum is subject not only to manipulations but also *to manifold* resections the latest being its complete removal along with the *stomach* bed *in the expansion of the* operation for carcinoma of the stomach (Appleby 1953) Portions most frequently incised partly or completely removed include the gastrocolic the gastrosplenic the lienorenal the phrenicogastric and the phrenicocolic ligaments and the transverse mesocolon Quick inattentive incisions into these ligaments may *cause sudden massive bleeding* as is typically the case in the region of the phrenicocolic ligament where the left epiploic artery may be coursing (Fig 41) and in the region of the gastrocolic ligament under which the superior mesenteric and its main branches are located Severe clamping of the gastrocolic ligament may tear *the* underlying vessels causing *them to bleed*

The omental tissue should always be handled with care and understanding for the omental blood vessels especially those comprising the large epiploic arc of Barkow (1793) situated in the posterior layer of the great omentum below the transverse colon play an important role in the collateral circulation of the spleen the liver and the stomach when *respectively considered the splenic the* hepatic or one of the arteries along the *greater curvature becomes occluded* (Figs 1 2 59 100)

In many operative technics, omental tissue is used for repair and packing to wit to cover sewn up perforation of gastric and duodenal ulcers to cover the gallbladder bed in cholecystectomies to prevent adhesions in serosal denudations in blind colostomies and in many other procedures

Unknown is the mechanism whereby *the great omentum moves to* different regions in the abdominal cavity Its torsion may have serious sequelae (Mann 1954) Torsion of the omentum according to Mann of the Chicago Medical School (1954) may simulate any acute abdominal surgical condition over 300 cases having been reported in the literature Since the right side of the omentum is more mobile *than the left it is* more *apt to be involved in torsion* *Mann maintains that* the presence of

blood or blood staining fluid in the abdomen should make the surgeon aware of this condition Omental torsion and the pathologic changes associated with it are discussed fully by Anton Jennings and Spiegel (1915) Unknown are the nature and the scope of the nerve supply to its blood vessels the omental nerves being few and the anatomic basis for the contraction and the dilation of its capillaries through capillary nerves and Rouget cells being largely problematical as shown by the author in a special attempt to solve this problem (1935 1936)

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wall of the primitive mesogastric peritoneal duplication (*great omentum*) and the posterior layer of the primitive transverse mesocolon the intervening two serosal layers (anterior layer of the primitive transverse mesocolon and primitive posterior layer of the great omentum) having become fused into connective tissue In the upper right quadrant of the body the anterior two layers of the great omentum are as a rule extensively fused with the pars mesocolonis omenti of its posterior layer In the upper left quadrant *however the two layers* are not fused allowing ready access to the omental bursa through the gastrocolic and the gastrolienal ligaments The length and the recumbency of the pars mesocolonis omenti (i e of the transverse mesocolon) show marked variations facts of surgical importance in surgical *gastrojejunostomies Often it is so* short as to necessitate an anterior or a precolic gastrojejunal anastomosis When long the relative avascular area of Riolan on the left permits the posterior or transmesocolonic route of operative approach

Terrains of Blood Supply

With the above anatomy in mind *the sources of blood supply to the great* omentum readily can be explained and understood Succinctly stated the anterior layer of the great omentum is the terrain of blood supply coming mainly *from the hepatic via the gastroduodenal* the right gastro epiploic and the latter s anterior epiploic (omental) branches (5 to 10) there being fewer of these from the left gastro epiploic (Fig 1)

The posterior layer of the great omentum has two terrains of blood supply viz that above and that *below* the transverse colon The latter constituting the pars libera omenti is the terrain supplied by the left gastro epiploic and its left epiploic (omental branch) which *at the lower one third* of the great omentum passes from the anterior to the posterior layer to establish the left limb of the arcus epiploicus magnus of Barkow (1793) situated 2 to 4 cm below the transverse colon The right limb of this arc is usually formed by the first or the second right epiploic which after its *origin from the right gastro epiploic* passes backward into the posterior layer of the great omentum (Figs 1 2, 59 100)

The part of the great omentum above *the transverse colon (i e pars mesocolonis* omenti or transverse mesocolon) is the terrain supplied by the vessels derived from two main sources (1) the posterior epiploic arteries stemming from the pancreatic vessels (*transverse pancreatic dorsal pancreatic a pancreatica magna*) which leave the inferior *border of the pancreas to* vascularize it —a sequence to the fact that the pancreas develops mainly in the posterior layer of the great omentum (2) branches from the middle colic which through *their vasa recta and arcades anastomose* with the descending posterior epiploics —a sequence to the fact that the posterior layer of the great omentum became fused with the anterior layer of the transverse *mesocolon*

Subsidiary vessels to the transverse mesocolon comprise (1) posterior epiploics which arise from the arc of Barkow and ascend to anastomose with the descending *posterior epiploics* and the vasa recta of the middle colic (2) some of the anterior epiploics which at *the* lower edge of the great omentum have turned upward to become posterior epiploics making similar anastomoses On all occasions the anastomoses of the posterior *epiploics* with *branches* of the middle colic occur on the anterior surface of the transverse colon *for developmentally* considered it was the posterior

layer of the great omentum that became fused with the anterior layer of the transverse mesocolon and the anterior surface of the transverse colon. Some of the long posterior epiploics sank directly into the transverse colon, thereby participating in its blood supply.

Anatomic details of the blood supply of the great omentum are as follows: There are two epiploic or omental arcs. The upper arc is subgastric in position, to wit, from 1 to 20 mm below the greater curvature. It is made by the anastomoses of the right and the left *gastro-epiploics coursing in the anterior* layers of the great omentum, i.e., in the gastrocolic and the gastrosplenic ligaments (Fig. 50). The lower arc, infracolic in position, is situated in the posterior layer of the great omentum midway between the transverse colon and the omentum's distal free end. It is made by the anastomosis of the right and the left epiploics, these being respective branches of the right and the left gastro-epiploics which have passed posteriorly (Fig. 2). The upper subgastric arc gives off short ascending branches to the anterior and the posterior surfaces of the stomach and the pylorus and the short and the long descending branches (anterior epiploics) which course downward in the anterior layer of the great omentum. The number of these descending anterior epiploic arteries varies considerably—commonly 5 to 10, in some instances as high as 15. The short anterior epiploics anastomose with one another and with neighboring long anterior epiploics. The latter descend to the free end of the great omentum, then turn upward and as posterior epiploics, for the most part, join the large epiploic arc of Barkow; others anastomose with posterior epiploics from the transverse *pancreatic or with branches* of the middle colic or sink into the anterior surface of the transverse colon.

The Large Epiploic Arc of Barkow

This widely scalloped arterial arc, situated in the posterior layer of the great omentum (retro-omental) 2 to 4 cm below the transverse colon, was first described by Barkow in 1793 as the arcus epiploicus magnus. Its decidedly varied structural composition accounts for its omission in texts of anatomy and surgery and accounts for the diversified descriptions of the arc given by Barkow, Haller, Winslow, Rio-Branco, Pigache, Worms, Arnauld, Dolgo-Saburoff and Henschen. The present account is based *on the observations of the author and on* those reported by Dolgo-Saburoff (1927). With the understanding that the right limb of the arc of Barkow is usually made by the right epiploic branch of the right gastro-epiploic and the left limb of the arc by the left epiploic from the left gastro-epiploic, the following 10 types can be categorized:

I. The entire arc is situated in the posterior layer of the great omentum, 2 to 4 cm below the transverse colon. It is the predominant pattern (Figs. 1, 2).

II. The right half of the arc is in the *anterior layer, the left half in the* posterior layer.

III. The left half is in the anterior layer, the right half in the posterior layer and linked to the transverse pancreatic or to the splenic via the dorsal pancreatic, which descends in the posterior layer of the great omentum.

IV. The right limb of the arc is made by an anterior epiploic other than the first.

V. The right arc is formed by two anterior epiploic arteries, the first going into the posterior layer.

VI. The right arc is formed by two arteries: an anterior epiploic, which stems from the right gastro-epiploic, and a posterior

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With the above anatomy in mind the sources of blood supply to the great omentum readily can be explained and understood. Succinctly stated the anterior layer of the great omentum is the terrain of blood supply coming mainly from the hepatic via the gastroduodenal the right gastro epiploic and the latter's anterior epiploic (omental) branches (5 to 10) there being fewer of these from *the left gastro epiploic (Fig 1)*.

The posterior layer of the great omentum has two terrains of blood supply viz that above and that below the transverse colon. The latter constituting the pars libera omenti is the terrain supplied by the left gastro epiploic and its left epiploic (omental branch) which at the lower one third of the great omentum passes from the anterior to the posterior layer to establish the left limb of the arcus epiploicus magnus of Barkow (1793) situated 2 to 4 cm below the transverse colon. The right limb of this arc is usually formed by the first or the second right epiploic which after its origin from the right gastro epiploic passes backward into the posterior layer of the great omentum (Figs 1 2, 59 100).

The part of the great omentum above the transverse colon (i e pars mesocolonis omenti or transverse mesocolon) is the terrain supplied by the vessels derived from two main sources (1) the posterior epiploic arteries stemming from the pancreatic vessels (transverse pancreatic dorsal pancreatic a pancreatica magna) which leave the inferior border of the pancreas to vascularize it —a sequence to the fact that the pancreas develops mainly in the posterior layer of the great omentum (2) branches from the middle colic which through their vasa recta and arcades anastomose with the descending posterior epiploics —a sequence to the fact that the posterior layer of the great omentum became fused with the anterior layer of the transverse mesocolon.

Subsidiary vessels to the transverse mesocolon comprise (1) posterior epiploics which arise from the arc of Barkow and ascend to anastomose with the descending posterior epiploics and the vasa recta of the middle colic (2) some of the anterior epiploics which at the lower edge of the great omentum have turned upward to become posterior epiploics making similar anastomoses. On all occasions the anastomoses of the posterior epiploics with branches of the middle colic occur on the anterior surface of the transverse colon for developmentally considered it was the posterior

existence of appreciable anastomoses between the arteries of the omentum and those of the colon Arnaud (1927) denying it completely On this basis it is believed generally that the scanty anastomotic twigs encountered in separating the omentum from the colon do not merit ligation But one artery near the splenic flexure according to William J Mayo (1916) needs to be tied in some instances The artery referred to is unquestionably a posterior epiploic descending from a pancreatic vessel (Fig 41) In their study of the blood supply of the colon in 10 specimens Steward and Rankin (1933) found only 2 cases in which the posterior arteries of the great omentum communicated with the arteries of the colon the uniting vessels in their opinion being but peritoneal twigs of the long terminal arteries

From an anatomic and a functional point of view it is quite obvious that the posterior omental (epiploic) arteries as well as those coming from the pancreatic vessels via the transverse mesocolon are not sufficiently large and numerous to substitute for the middle colic when the latter becomes occluded However their presence and anastomotic connections may account for the fact that in cases of severe injury to the middle colic or of an interruption of one of its main branches the transverse colon at times actually remains viable (Fig 41)

Points to be emphasized and remembered with regard to the large infracolic arc of Barkow are (1) its intimate connection with the blood supply of the anterior layer of the great omentum (2) it furnishes the main blood supply to the pars libera of the posterior layer of the great omentum (3) it participates in the blood supply of the transverse mesocolon its ascending posterior epiploics anastomosing with the posterior epiploics derived from the pancreatic vessels (especially from the transverse pancreatic the dorsal pancreatic and the a pancreatica magna) and which embryologically considered constitute the primary blood supply to this mesentery (4) it participates at least to some extent in the blood supply of the transverse colon its ascending posterior epiploics anastomosing with the vasa recta of the middle colic or with their arcades on the anterior surface of the transverse colon whereas the main branches of the middle colic reach the colon on the posterior surface (5) it is an excellent collateral pathway for the spleen and the liver when either organ artery is blocked and for the stomach via the right epiploic joining the arcus arteriosus ventriculi inferior made by the right and the left gastro epiploic arteries (6) it cannot be relied upon to take over the blood supply for the transverse colon when the middle colic is severed albeit the blood supply coming from its ascending vessels (posterior epiploics) can explain the cases of maintenance of viability of the transverse colon following severe injury of the middle colic artery or of its main right or left branch

epiploic stemming from the transverse pancreatic

VII A duplication of the lower segment of the arc in the posterior layer

VIII Two complete arcs one in the anterior layer one in the posterior layer the right limb of the posterior arc being linked to the transverse pancreatic via a posterior epiploic or dorsal pancreatic

IX The entire arc lies in the anterior layer of the great omentum except for its medial distal portion which is in the posterior layer

X The entire arc or a major portion of it lies above the transverse colon a rare pattern and seen but a few times in 500 bodies

Characteristically in all observed patterns the left limb of the arc of Barkow was made by the left epiploic given off by the left gastro-epiploic as it coursed in the gastrolienal ligament The site at which the left epiploic quits the anterior layer of the great omentum to become situated in the posterior layer of the great omentum varied from its point *of origin from the left gastro-epiploic* (bifurcation of the latter) to the lower one third of the great omentum

The large infracolic epiploic arc of Barkow in the posterior layer of the great omentum receives the anterior epiploic arteries which after their origin from the right and the left gastro-epiploics descend in the anterior layer of the great omentum to the latter s free edge where they turn upward and as posterior epiploic arteries ascend in the posterior layer to join the arc *Some of the anterior epiploic* arteries anastomose with the vasa recta of the middle colic others sink into the anterior surface of the transverse colon or anastomose with the posterior epiploics coming from the pancreatic vessels (Fig 100)

A second group of posterior epiploic arteries take origin *from the infracolic* arc of Barkow ascend to the anterior surface of the transverse colon where they sink *into the transverse colon and* anastomose with the vasa recta of the middle colic or with their arcades or anastomose with the long posterior epiploics coming from the pancreatic arteries A third group of posterior epiploics take origin from the pancreatic arteries (transverse pancreatic dorsal pancreatic a pancreatica magna) and descend as short and long branches The short ones sink directly into the transverse colon or anastomose with the middle colic via the vasa recta or their arcades The long ones anastomose with ascending branches from the large epiploic arc (Fig 100)

Collectively considered the anterior layer of the great omentum has long arteries (the anterior epiploics) which vary in number from 5 to 15 In the posterior layer the arteries (posterior epiploics) are prevailingly short less numerous (4 to 7) and *do not* anastomose as extensively as do the anterior epiploics

Relation of the Omental Arteries to Those of the Transverse Colon

Surgical Considerations A striking discrepancy exists among anatomists and surgeons regarding the extent and the character of anastomoses between the omental arteries and those of the transverse colon Many anatomists in the past have made the observation that the transverse colon receives a blood supply not only from the middle colic but also from the arteries of the great omentum (*Haller Hyrtl Hildebrand* Arnold Cruveilhier Fort Testut Gray Cunningham Piersol) With the exception of Dolgo Saburoff (1927) and Henschen (1928) who gave substantial support to the view of the anatomists most surgeons have not been able to verify the

colon not only as regards major arteries but also as to anatomic details of the termination of long and short branches to the gut wall. Their report covers an investigation of 40 specimens injected with a celluloid material or injected with an opaque material subsequently examined in roentgenograms. A perusal of their excellent article is convincing evidence as to the variability of the blood supply to the large bowel. Typical observations made by the authors were:

1. The middle colic through a large branch or through an accessory middle colic supplies the left side of the transverse colon in only 37 per cent of the cases. Occasionally the middle colic trifurcated or had four branches. In two cases it was absent, being replaced by large branches from the left colic.

2. In 10 per cent an accessory middle colic arose from the superior mesenteric above the point of origin of the middle colic and ran to the left of the mesocolon to anastomose with the marginal artery of Drummond near the splenic flexure.

3. In 27 per cent the ascending branch of the left colic did not extend to the splenic flexure, and in 63 per cent it passed above the flexure and supplemented the marginal artery in the region of the left transverse colon.

4. The right colic arose from the superior mesenteric in 40 per cent, from the middle colic in 30 per cent and from the ileocolic in 12 per cent, while in 18 per cent no artery that corresponded in course and distribution to the right colic could be found. When the right colic was small, it was compensated for by a large middle colic or ileocolic vessel.

Steward and Rankin found variants in the main arterial pattern of the colon to occur in such a high frequency as to make it essential to deal with each case separately. They concluded that in all instances a main colic artery should be ligated *purposefully after palpation for pulsations* and only when occasion demands such ligation.

In conformity with the observations of Steward and Rankin with regard to variants in the arteries of the colon are those of numerous other investigators, to wit: Waldeyer, who stated that the right colic has an independent origin from the superior mesenteric in about one half of the cases; Jamieson and Dobson, who found the right colic to be a direct branch of the superior mesenteric in 50 per cent and of the ileocolic in 30 per cent; Adachi, who found an accessory middle colic 10 times in 54 cases; Henle, who reported a case of two middle colic arteries and several cases where branches of the superior and the inferior mesenteric arteries replaced the middle colic; Cruveilhier, who spoke of two left colic arteries; Henle and later Delannoy, who reported the occurrence of two superior mesenteric arteries; Moynihan, who found an accessory middle colic running directly toward the middle of the transverse colon; Riolan, who found an accessory middle colic (arc of Riolan) connecting the superior mesenteric with the superior left colic artery; Okinczyc, who noted that the anastomosis between the artery of the right and the transverse portions of the colon are often meager and slender; Merkel and later Lockhart-Mummery, who stated that an anastomosis between the left and the middle colic occasionally does not take place; Henle, Merkel and Cunningham, who reported an absence of the inferior mesenteric, it being replaced by branches from the superior mesenteric. Numerous investigators have reported an aberrant origin of the middle colic from the gastroduodenal, the right gastro-epiploic and the celiac, as well as an aberrant origin of the superior mesenteric itself via a common celiacomesenteric trunk, the most recent report of the latter origin being that of Munger (1941).

Sequebantur omnes Vesalium, magnum virum sed in vasorum corporis humanis cognitione non perinde perfectum ut in ossibus musculosque describendis fuit

—Thus wrote Haller (1745) to alert his readers to a deeper appreciation of arterial variations. How true today of the infracolic organs if for Vesalius we substitute textbooks!

12

Blood Supply of the Small and the Large Intestines

The Superior Mesenteric Artery

Review of the Literature

The author's subsequent investigative account of the superior mesenteric artery will deal mainly with its varied mode of origin and with its varied participation in the blood supply of the supramesocolic organs, it having been *studied solely from these points of view*. As a guide and a safeguard to the surgeon in the ever-increasing, varied and difficult operative procedures on the infracolic organs (esophagojejunostomies, resections of the small bowel, radical colectomies, prostatectomies, renal resections and ureteral transplantations, removal of the adrenals, operative procedures for utero-ovarian and rectal malignancies, pelvic evisceration, etc.) a *descriptive atlas on the varied arterial blood supply of the infracolic organs* comparable with the one at hand is urgently needed. It will take many years of investigative work on the part of an anatomist or a surgeon to prepare such an atlas, but when it is completed, it will be referred to and studied by those surgeons who more and more have come to realize that a knowledge of anatomy in surgical procedures is the best safeguard to avoid surgical injuries.

Patterns of the superior and the inferior mesenteric arteries, as well as those of the renal, the suprarenal and the internal hypogastric arteries, are extremely varied and far different from those described and illustrated in standard texts of anatomy and surgery, as voiced to the author in particular in regard to the suprarenal glands by Dr. Sherman A. Eger of the surgical staff of Dr. Thomas A. Shallow of Jefferson Medical College (1953). In the last 200 years very few anatomic investigations have been made on an extensive scale to help augment our knowledge on the variability of the arteries supplying the lower abdominal and the pelvic organs. Of reports on the variant vascularization of the colon, the rectosigmoid and the rectum, those of the following men are of special interest and significance: Manasse (1907), Sudeck (1907), Rubesch (1910), Drummond (1914), Ssoson-Jaroschewitsch (1924), Adachi (1928), Steward and Rankin (1933), Sunderland (1942), Bacon and Smith (1948), Toracca (1949) and Greenberg (1950), nearly all of these authors being surgeons.

The work of Steward and Rankin (1933) from the Mayo Clinic of the University of Minnesota is the most comprehensive on the vasculature of the

Greenberg (1950) in a study of 71 injected autopsy specimens was able to demonstrate an adequate anatomic linkage between the sigmoid ima or lowest sigmoid and the divisions of the superior hemorrhoidal in 51 1 per cent of the cases The sigmoid arteries encountered fell into the following groups single 26 per cent two branches 36 per cent three branches 19 per cent four branches 19 per cent He found the sigmoid ima or lowest sigmoid to be a constant artery that supplied the rectosigmoid and the upper rectum and that it anastomosed with adjacent sigmoid arteries to complete the arcade of the marginal artery of Drummond in 81 per cent of the cases Dixon (1918) emphatically states that Sudeck s critical point is not at all critical a viewpoint shared partly by Bacon and Smith of Temple University (1948) who suggested that *transillumination of the mesentery* at operation is the best method to ascertain the actual existent vascular pattern (idem Torraca of South America)

Anatomic and Embryologic Considerations

The superior mesenteric artery supplies the third part of the duodenum a portion of the head and frequently an extensive area of the body of the pancreas the entire small intestine (jejunum and ileum) and the large intestine nearly up to the left colic flexure

After its origin from the celiac artery behind the pancreas the superior mesenteric enters the root of the mesentery that begins above the ascending part of the duodenum to the right of the duodenojejunal flexure under the line of attachment of the transverse mesocolon The superior mesenteric artery and vein emerge from beneath the pancreas in the neck region (incisura pancreatis) the uncinate process of the pancreas lying behind the mesenteric vessels Before entering the root of the mesentery and accordingly still behind the pancreas the superior mesenteric gives off the *inferior pancreaticoduodenal to* supply the third part of the duodenum and the lower region of the head of the pancreas and in many instances gives rise to an aberrant right hepatic occasionally to the entire hepatic artery

After crossing in front of the fourth or ascending part of the duodenum and after leaving its inferior border a bit to the right of the duodenojejunal flexure the superior mesenteric passes obliquely down in the root of the mesentery Here between its two layers it proceeds obliquely downward from left to right to the right iliac fossa to within 6 inches of the ileocecal junction where it ends by uniting with its own ileal branch of the ileocecal artery In its downward course the superior mesenteric crosses the duodenum the aorta the inferior vena cava the right ureter the genitofemoral nerve the testicular (ovarian) vessels and the fascia of the psoas major muscle

The site of emergence of the superior mesenteric from beneath the pancreas and the fact that it crosses in front of the duodenum warrant emphasis and consideration Since the lumbar segment of the vertebral column is convex forward the superior mesenteric must pass forward as well as downward from its point of origin on the aorta at vertebral level lumbar I After it has crossed the caudal part of the duodenum it passes abruptly backward and because of this relationship readily may become involved in duodenal obstruction when unusual tension is placed on the artery by massive neoplastic growth in the mesentery As early as 1849 Rokitanski advanced this relationship as a possible cause of *acute dilatation of the stomach*

Another important relationship of the superior mesenteric artery is the fact that the left renal vein as it crosses the

Of decided surgical import especially in cholecystectomies and in resections of the head of the pancreas is *the fact that,* in every tenth patient (more accurately in 10 per cent of the population), the superior mesenteric gives rise to a right hepatic artery which in three fourths of the cases is a replaced (i e the only right) hepatic present while in one *fourth of the cases it is an accessory hepatic* (Figs 84 90) An incidence of 10 per cent was reported by Adachi in 252 bodies by Descomps in 50 by Rio Branco in 50 by Thompson in 50 while Lipschutz noted 8 per cent in 83 bodies Cavalcanti (1951) reported 10 per cent Percentages above 10 per cent were reported by Susloff, 12 per cent in 131 bodies Grant 12 per cent in 165 Daseler *et al 14 per cent in 500 Häller 17* per cent in 30 Michels 17 per cent in 200 Flint 21 per cent in 200

In many instances the entire hepatic arises from the superior mesenteric 5 cases having been observed by the author in 200 bodies (Figs 19 38 53) (Adachi 3 in 252 bodies Lipschutz 3 in 83 Browne 4 in 280 Rossie and Cova 4 in 102 Susloff 6 in 131 Daseler *et al 22 [4 4 per cent] in 500 bodies)* Cavalcanti (1951) reported 2 per cent

From a historical point of view it is interesting to note that in the diagrams of Vesalius (1538) the inferior mesenteric is well delineated whereas the superior mesenteric and the celiac are confused Although Haller gave the first description of the anastomosis of the colic arteries it was Hamilton Drummond (1913) of England who first used the term marginal artery to designate the continuity of the scalloped anastomotic arches along the wall of the colon from the ileocecal junction to the sigmoid colon In postmortem investigations he tied off the main colic and the sigmoid arteries at their origin and noted that material injected into the ileocolic artery reached and filled the sigmoid vessels

Although Jean Riolan anatomist at the University of Paris, strenuously opposed Harvey s thesis (1628) of the circulation of the blood (despite the fact that Harvey referred to him as prince of anatomists) his name has become associated with the anastomoses of the mesenteric arteries and in particular with the accessory middle colic artery of superior mesenteric origin that courses to the left of the transverse colon in the so called vascular area of Riolan to become interposed between the left branch of the middle colic and the ascending branch of the left colic (Fig 41)

Previous to Drummond on the basis of injections and roentgenologic studies *Sudeck (1907) had called attention* to the anastomotic character of the artery running along the wall of the lower colon He emphasized his observation that if a ligation is placed *below* the *origin of the lowest sigmoid artery,* few of the rectal vessels become filled Sudeck s critical point *(which according* to Sudeck is located on the inferior mesenteric just above the origin of the last sigmoid) has been checked and investigated by Ssoson Jaroschewitsch (1924) Sunderland (1942) Bacon and Smith (1948) Toracca (1949) and Greenberg (1950)

According to Toracca the sigmoid patterns are extremely varied Sudeck s critical point being present in 90 per cent of 30 cases As observed by him the inferior mesenteric gives rise to (1) the superior left colic (2) the sigmoid *trunk (3) the superior* hemorrhoidal The sigmoid trunk becomes subdivided into (a) the superior or left sigmoid which anastomoses with a colic branch (b) the middle sigmoid (c) *the sigmoid* ima (rectal or inferior sigmoid) the latter anastomosing with the superior hemorrhoidal draining blood to the rectosigmoid segment

shoe-shaped duodenum crosses the midline and the aorta, allowing the duodenojejunal flexure to receive a blood supply not only from the jejunal branches of the superior mesenteric but also from branches of the inferior pancreaticoduodenal and the retroduodenal arteries (7) there is a persistence (from the superior mesenteric artery) of the vitelline artery which courses in a strand of connective tissue from the ileum to the umbilicus where it communicates with the epigastric and gives off a branch to the round ligament of the liver. The vitelline artery represents a remnant of the primitive omphalomesenteric artery that during early fetal life passed through the umbilical cord to become distributed on the surface of the yolk sac.

The occurrence of a celiacomesenteric trunk, i.e. one in which the celiac and the superior mesenteric arise from a common trunk, has repeatedly been reported in the literature, its average incidence being about 1 per cent. The mode of formation of the celiacomesenteric trunk can be accounted for from both an ontogenetic and a phylogenetic point of view. Buhler (1904) explained the phenomenon on the basis that in the embryo the two vessels had a common stem. Tandler (1904) explained it on the basis that the roots of the omphalomesenteric artery, which ordinarily should give rise to the celiac, disappear but the ventral longitudinal anastomosis between the celiacal roots and those of the superior mesenteric artery persists, thus giving rise to a celiacomesenteric artery as exemplified in *Talpa europea*, where the celiacomesenteric trunk is the normal pattern, as it likewise is in the frog[1] and in many lower forms (Schabadash 1935).

[1] As shown and illustrated by Adelle Virginia Michels (now Mrs Sidney Larsons), daughter of the author, at Ursinus College, Collegeville, Pa (1952) in her B.S. thesis under the late biologist Dr Brownlack in an investigation of 150 frogs.

Practically all of the variations of the celiac and the superior mesenteric arteries according to Tandler can be explained on the basis of a persistence of aberrantly broken sections of the primitive longitudinal anastomosis between the superior mesenteric and the celiac, the broken segments carrying the respectively caught, i.e. displaced, arteries. Tandler's hypothesis offers a plausible explanation for the formation of a celiacocolic trunk, in which the middle colic or an accessory middle colic arises directly from the celiac and courses downward behind the pancreas to reach the transverse colon, as observed on several occasions by the author (Figs 20, 26, 41). Persistence of both the right and the left splanchnic vessels, from which through fusion the superior mesenteric is formed, may result in the formation of a double superior mesenteric, incidence of which has been reported repeatedly in the literature.

Observations in 200 Dissections

In the 200 specimens investigated the superior mesenteric artery arose from the anterior aspect of the aorta at an average vertebral level of lumbar I, a little below the celiac, which in most instances it equaled in size and at times surpassed. The interval between its site of origin from the aorta and that of the celiac varied from 1 to 22 mm, commonly being 1 to 6 mm (60 per cent). In two bodies it arose from a common celiacomesenteric trunk. When a right hepatic or an entire hepatic arose separately from the superior mesenteric, a hepatomesenteric trunk was formed (Figs 53, 84, 89). In one instance the splenic took origin from it, forming a lienomesenteric trunk (Fig 67), and in one case the superior mesenteric gave off both the right hepatic and the splenic, thereby forming a hepatolienomesenteric trunk. Variants of these split celiac and mesenteric trunks have al

vertebral column to join the inferior vena cava on the right side is precariously clamped between the superior mesenteric plus underlying duodenum and the aorta much like a nut is clamped in a nut cracker Excessive backward pressure on the duodenum by the artery may cause disturbances in the renal blood flow

Situated to the left of the end of the duodenum i e, at the duodenojejunal flexure are prominent folds of the peritoneum Of the many present one covers the ascending inferior mesenteric vein another covers the ascending branch of the left colic artery *The two vessels combined form a half circle or arc known as the vascular arc of Treitz* Its significance and location are well worth noting for the vessels contained in the arc may be injured readily in a surgical approach to the duodenal fossa in resections of the jejunum or in a repair of internal or retroperitoneal hernia due to volvulus

Like the celiac, the superior mesenteric shows many embryologic irregularities in contour origin and configuration The first part of the artery for an inch or more may be indented in spiral form a vestige of the primitive rotation of the midgut which took place counterclockwise around it, as an axis to 270° the artery itself making a 180° rotation A vestige of the primitive relation is the varied origin of the inferior pancreaticoduodenal In most cases it arises from the right side of the superior mesenteric rotation of the gut having taken place distal to its site of origin from the superior mesenteric (Fig 49) Frequently the inferior pancreaticoduodenal arises from the left side of the superior mesenteric or from a first or second jejunal branch thereby attesting to the fact that rotation of the gut took place proximal to the point of origin of the inferior pancreaticoduodenal (Figs 72 90) As a result of the dextrorotation of the midgut about the superior mesenteric artery as its axis and the rotation of the latter in the process, the mode in which the superior mesenteric gives off its intestinal and colic branches in the adult is just the reverse of what the order was in the primitive unrotated sagitally placed gut *In the adult, the first branch* of the superior mesenteric is the inferior pancreaticoduodenal, a remnant of the primitive condition the artery staying on the right side of the primitive unrotated artery Thereafter, from the concave side of the artery arise the middle colic the right colic and the ileocolic the terminal or ileal branch of which unites with the terminal end (i e the last intestinal branch) of the superior mesenteric From the convex left side of the latter arise 12 to 20 jejunal and ileal branches which, in the unrotated gut arose from the right side of the superior mesenteric and constituted its first branches

Other embryologic peculiarities of the superior mesenteric due to the dextrorotation of the gut are (1) the transverse colon crosses it anteriorly the ascending and the descending colon lie lateral to it (2) the third part of the duodenum lies behind it the artery and the root of the mesentery crossing it in front (3) the uncinate process of the pancreas lies behind the superior mesenteric vessels (4) the neck of the pancreas is related posteriorly to the portal vein and the junction point of the superior mesenteric vein and the splenic vein a sequence to the backward swing of the head of the pancreas in a longitudinal 90° rotation of the duodenum (5) the location of the superior mesenteric vein is to the right of the superior mesenteric artery a sequence to the fact that the latter arises from the aorta a midline structure while the inferior vena cava end recipient of the hepatic blood is developed on the right side (6) the ascending portion of the horse

municate with similar branches given off by the branch above and the branch below In this manner a series of scalloping primary loops or arcades are formed which as a whole run parallel with the intestine By a process of division and union of branches given off by the primary arcades secondary arcades and in like manner tertiary quaternary and even a network of quinary loops or arcades are established

The ultimate or most distal arches give rise to a very large number of straight jejunal and ileal branches (vasa recta) These do not anastomose but course to the gut wall where each terminal divides into two branches one passing to the anterior the other to the posterior surface of the gut usually in alternate order The innumerable terminal branches or vasa recta end as end arteries by forming anastomotic arterial rings A continuous vascular network is thereby established throughout the length of jejunum and the ileum thereby equalizing the blood supply and allowing for a rapid collateral circulation when through pressure exerted by peristalsis any action of the intestine temporarily becomes deprived of its blood supply Proximally the vascular network communicates with the inferior pancreaticoduodenal distally it is anastomosed with the terminal branch i e the last intestinal branch of the superior mesenteric In their course to the gut wall the intestinal arteries supply the mesentery and the mesenteric lymph nodes distributed in it

Beginning with the jejunum there is a progressive increase in the number of arcades or scalloping loops formed by the intestinal arteries In the first quarter of the jejunum the vasa recta arise from single arcades in the second quarter from double tiers of arcades in the third quarter from triple tiers and in the fourth quarter from quadruple tiers An examination of the character of the tiers by holding them up to the light will indicate roughly the level of the jejunum in hand and allow its differentiation from a region of the ileum where disposition of the vessels is more complex arcades are less scalloped and the vasa recta are shorter

3 The Middle Colic This surgically considered highly important artery arises from the front or from the concave side of the superior mesenteric at the lower border of the pancreas a bit below the origin of the inferior pancreaticoduodenal Passing downward and forward in the right half of the transverse mesocolon at a variable distance from the gut wall (5 to 7 cm) it divides into a right and a left branch which anastomose respectively with the ascending branch of the right colic and the ascending branch of the left colic of the inferior mesentery to form primary and secondary arches from which terminal straight branches (vasa recta) are given off to the transverse colon with the exception of the latter s distal left end (splenic flexure)

In contrast with this typical picture the middle colic according to Steward and Rankin may trifurcate or have four branches In 10 per cent they found it to be double the accessory middle colic arising a bit above the normal vessel In 27 per cent they encountered a large branch of the middle colic which ran to the splenic flexure to reinforce the marginal artery In the present study there were many instances in which before bifurcating the middle colic or an accessory middle colic gave rise to a dorsal pancreatic which then ascended to the pancreas (Fig 42) In some instances the middle colic arose from the celiac and in its descent behind the splenic vein and the pancreas gave off the dorsal pancreatic and its transverse pancreatic branch (Figs 20 26 40)

ready been discussed Curtly summarized the superior mesenteric may arise in conjunction with one two or all of the branches of the celiac and in addition may give rise to an aberrant right hepatic a gastroduodenal a right gastro epiploic and a transverse pancreatic artery (Figs 36, 67 31 57)

Constant Branches of the Superior Mesenteric

The constant branches of the superior mesenteric are (1) the inferior pancreaticoduodenal (2) the intestinal (jejunal and ileal) (3) the middle colic (4) the right colic (5) the ileocolic Inconstant branches frequently met with are (6) the dorsal pancreatic (7) the transverse pancreatic (8) an accessory or replaced right hepatic (17 per cent in this study) or the entire hepatic (5 cases) (9) *an accessory middle colic* (10 per cent) (10) the ramus anastomoticus of Buhler connecting the celiac or one of its branches with the superior mesenteric or one of its branches (Fig 29) In some instances the splenic the gastroduodenal the superior pancreaticoduodenal *the right* gastro epiploic and even the cystic artery may take origin from it (Figs 2 31) The vitelline artery remnant of the fetal omphalomesenteric artery may persist as a branch of the superior mesenteric in a strand of connective tissue connecting the ileum with the umbilicus and *lead to serious* rupture in the infant

1 The Inferior Pancreaticoduodenal It arises in most instances (60 per cent) as a single vessel from the right side of the superior mesenteric less frequently from the left side of this artery or from *its first or second jejunal branch* (Figs 49 42 72) It courses upward behind the superior mesenteric vein and beneath the ascending serosa layer of the transverse mesocolon (duodenocolic ligament) and follows the upper border of the third part of the duodenum where on the posterior surface of the head of the pancreas it divides into an anterior and a posterior branch The anterior branch gives off 3 to 4 long branches (vasa recta) to the anterior surface of the transverse and the ascending portions of the duodenum and a few pancreatic branches while coursing to the anterior surface of the pancreas where it unites with the superficially placed superior pancreaticoduodenal In short the anterior and the posterior branches of the inferior pancreaticoduodenal receive respectively the anterior and the *posterior arcades* and in this respect constitute a common inferior pancreaticoduodenal (60 per cent) (Fig 76)

In many instances there are two inferior pancreaticoduodenals the one for the posterior pancreaticoduodenal arcade joining the superior mesenteric *directly at a much higher level or* uniting with its first or second jejunal branch (Figs 50 90) Aberrant origins of the inferior pancreaticoduodenal as either a single or a double vessel comprised its origin from the left side of the superior mesenteric (Fig 12) from its first or *second jejunal branch (Fig 72)* from a dorsal pancreatic derived from the superior mesenteric (Fig 46) from an aberrant right hepatic of superior mesenteric origin (Figs 84 88) It may communicate with the celiac by means of an appreciably large vessel usually a *branch of the dorsal pancreatic* (Fig 74) or with the hepatic (Fig 69) or the transverse pancreatic (Fig 76)

2 The Intestinal Arteries The intestinal arteries comprise two groups jejunal and ileal Varying from 12 to 20 in number they arise from the left convex *surface of* the superior mesenteric mainly after it enters the mesentery the upper intestinal arteries being considerably larger than the lower As they radiate out between the two layers of the mesentery each intestinal artery divides into two branches that com

ing a single or double arc from which several terminal branches (vasa recta) are given off to the last 6 inches of the ileum

The other three branches of the ileocolic comprise (1) the anterior cecal which courses through the superior cecal fold that covers the superior ileocecal fossa to become distributed on the anterior surface of the cecum (2) the posterior cecal which passes behind the ileum to ramify on the back of the cecum (3) the appendicular artery which usually arises from the posterior cecal passes behind the ileum to course in the free edge of the meso appendix a triangular fold of peritoneum that lies between the appendicular artery and the vermiform process and which is continuous with the left (dorsal) layer of the mesentery of the ileum The so called bloodless fold of Treves spans the inferior cecal fossa as it passes from the ileocecal junction to the meso appendix It contains fine arterial twigs but as a rule has no vessel of appreciable size

The site of origin of the appendicular artery is extremely varied From an examination of 200 specimens Anson (1951) depicted nine different types of origin the artery arising from the ileal branch of the ileocecal in 35 per cent from the end branching point of the ileocolic in 28 5 per cent and early from an anterior cecal in 13 5 per cent the other types being variations of an origin from the posterior and the anterior cecal and even from the right colic (1 5 per cent) or the ileocolic (1 per cent) The appendicular artery may be double In an examination of 60 specimens Shah and Shah encountered double appendicular arteries in 30 per cent one artery arising from the anterior the other from the posterior cecal or both arteries arising from the anterior or the posterior cecal

Odd and very surprising to the author was one case in which an appendicular artery arose from the dorsal pancreatic of celiac origin which had made its way down to the ileocecal junction The case was matched by one in which the dorsal pancreatic of similar origin descended to anastomose with the left colic distal to its bifurcation point The strange variations may be explained readily on the basis that in some instances the middle colic is actually an enlarged dorsal pancreatic i e a vessel which takes origin from the celiac descends behind the pancreas where it gives off the dorsal pancreatic then proceeds in the transverse mesocolon to function as the middle colic from which an ileocolic or a branch to the left colic may arise

Inconstant Branches of the Superior Mesenteric

Having just considered the 5 constant branches of the superior mesenteric its inconstant branches comprise (6) the dorsal pancreatic (7) the transverse pancreatic (8) an aberrant right hepatic (accessory or replaced) and (9) an accessory middle colic these being the most frequent Typically the dorsal pancreatic arises from the first part of the splenic or from the first part of the hepatic and descends into the pancreas When it arises from the superior mesenteric (14 per cent in this study) it ascends behind the splenic vein and after entering the pancreas gives off its characteristic transverse pancreatic branch the latter being superficial for a centimeter or more before running its course along the inferior border of the pancreas at the tail end of which it anastomoses with the arteria pancreatica magna or the a caudae pancreatis branches of the splenic (Figs 46 61)

The transverse pancreatic may become displaced from the dorsal pancreatic and take a direct and separate origin from the superior mesenteric (Fig 62)

An origin of the middle colic from a replaced right hepatic stemming from the superior mesenteric was noted in one case (Fig 36) In two instances the middle colic the superior pancreaticoduodenal and the right gastro epiploic arose from the superior mesenteric via a common trunk, the gastroduodenal of hepatic origin becoming dissolved into the retroduodenal and a branch which united with the right gastro epiploic (Fig 51) As previously stated the splenic may arise separately from the superior mesenteric forming a heno mesenteric trunk When the splenic arises in conjunction with a right hepatic artery a hepatolienal mesenteric trunk is formed In both cases the splenic immediately courses up behind the pancreas to reach its upper border where it follows its normal course (Figs 67 17)

The fact that a gastroduodenal or a right gastro epiploic may arise from the superior mesenteric warrants repeated recollection (Figs 67 31) Extremely interesting was the case in which the gastroduodenal after its origin from the superior mesenteric swung around the common bile duct from back to front but before doing so gave off the superficial cystic (Fig 46) A direct origin of the cystic from the superior mesenteric was never observed in this series this being the closest approach made Origin of the cystic from the superior mesenteric was reported by Daseler et al Susloff Vincens and Lipschutz the latter having observed three instances of it Belou (1915) observed an origin of the superficial cystic from the superior mesenteric in one case in 150 bodies

4 **The Right Colic** Markedly varied in its origin this artery typically arises from the right or concave surface of the superior mesenteric usually as a separate vessel or via a common trunk of variable length that divides into the right colic and the ileocolic the mode of the latter type of origin occurring in about one third of the cases Coursing behind the peritoneum the right colic crosses the ureter and the testicular (ovarian) vessels and nearing the ascending colon divides into an ascending and a descending branch the former anastomosing at times very meagerly with the descending branch of the middle colic the latter with the ascending or colic branch of the ileocolic From the scalloped arches thus formed arise a variable large number of straight terminals (vasa recta) which become distributed to the upper two thirds of the ascending colon and to the right portion of the transverse colon

This pattern of the right colic, according to Steward and Rankin may be considerably altered for in their specimens it arose from the superior mesenteric in 40 per cent from the middle colic in 30 per cent and from the ileocolic in 12 per cent while in 18 per cent it was absent When absent the right colic is replaced by a descending branch of the middle colic and an ascending branch of the ileocecal In some instances it is double one arising from the middle colic the other from the ileocolic

5 **The Ileocolic** This surgically considered highly important artery arises from the concave side of the superior mesenteric about halfway down its length either independently or via a common trunk with the right colic Passing behind the peritoneum and crossing the same structures as the superior mesenteric at a variable distance from the colon it divides into an ascending and a descending branch The ascending branch unites with the descending branch of the right colic the descending branch divides into four branches the last of which (the ileal) courses in the mesentery where it unites with the end (i e the last intestinal) branch of the superior mesenteric form

which united with the left branch of the middle colic and a lower branch which united with the ascending branch of the left colic (Fig 11) When of superior mesenteric origin the accessory middle colic in many instances gave off the dorsal pancreatic branch before proceeding to the splenic flexure (Fig 12) The accessory middle colic sometimes known as the artery of Riolan may take a course parallel with that of the marginal branch of the left colic connecting the latter with the superior mesenteric thus establishing the arc of Riolan

Many developmental peculiarities of the relationship between the middle colic and the accessory middle colic and the branches of celiac origin especially the gastroduodenal and the right gastro epiploic have already been considered While most of these relationships defy memorization of them in detail one anatomic fact should always be borne in mind viz that in many instances an anastomotic connection between the superior mesenteric its middle colic or its accessory middle colic branch is established behind the pancreas with one or more branches of celiac origin either by a separate vessel—the ramus anastomoticus of Buhler (Fig 29)—or by a ramifying branch of the dorsal pancreatic (Figs 10 41 42 51 61 69 74) The anastomotic arteries are predominantly small less than 1 mm but occasionally they are very large (2 mm) especially when connecting the superior mesenteric with the hepatic or the right gastro epiploic (Figs 29 59) For the most part they are located behind the portal vein or the junction point of the superior mesenteric vein and the splenic vein The presence of such anastomotic vessels is due ultimately to the persistence of a direct primitive longitudinal anastomosis between the roots of the celiac and the superior mesenteric arteries as shown by Tandler in the human embryo When large the ramus anastomoticus affords a collateral circulation between the supracolic and the infracolic organs (Fig 29)

Since one or more of the branches of the dorsal pancreatic or of the transverse pancreatic frequently emerges from the inferior border of the pancreas to course in the transverse mesocolon and there to establish connections with the regional arteries (in particular with the marginal artery of Drummond) a short description of the latter and the vasa recta is hereby included

Marginal Artery of Drummond and Sudeck s Point

A knowledge of the variability of the marginal artery of Drummond is of great interest and importance to the surgeon for as emphasized by Steward and Rankin radical surgical procedures on the colon are always fraught with the danger of *sepsis abdominal peritonitis and gangrene in the wall of the bowel from ischemia*

As usually interpreted the marginal artery of Drummond (1913) is made up of the end of the superior mesenteric and the anastomotic adjacent branches of the ileocolic the right colic the middle colic the upper left colic and the lower left colic (sigmoid) arteries According to Steward and Rankin the architectural arrangement of the blood vessels to the colon is comparable with a rubber tired wheel having few irregularly spaced spokes the latter representing the main colic arteries the rubber tire representing the continuous uninterrupted marginal artery It is generally believed that if the marginal artery is left intact while tying off an individual colic artery viability of the colon is not interfered with nor will gangrene eventuate after operation for the marginal artery through its anastomotic scalloping primary and secondary loops or arcades may be relied upon

*In one instance of such origin the trans*verse pancreatic was of such a large size *(15 mm in length 5 mm in width)* as to constitute an a splenica secunda which *with the obliteration of the or*dinary splenic could have furnished the entire blood *supply to the spleen* In this same specimen the inferior pancreaticoduodenal was likewise very large (diameter of 7 mm) and arose at the same level as the transverse pancreatic (Fig 121)

Today every surgeon is well aware of the fact that *in at least 10 per cent of the population, a right hepatic arises from the superior mesenteric behind the pancreas* the incidence in this study being 17 per cent The right hepatic may be the only one present or it may be an accessory vessel supplementing the normal celiacal right hepatic Not infrequently the entire hepatic arises from the superior mesenteric instead of from the celiac 5 cases having been encountered in this study (Figs 19 38 53)

In the 34 cases of aberrant right hepatics from the superior mesenteric observed by the author in 200 specimens 25 were replaced 9 were accessory (Figs 84 89) In the 71 cases encountered by Daseler et al 56 were replaced 15 were accessory Roughly then about three fourths of the right hepatics stemming from the superior mesenteric are *replaced right hepatics*—i e instead of coming from the common hepatic above the pancreas they arise from the proximal part of the superior mesenteric behind the pancreas and ascend to the gallbladder region mostly behind the portal vein and the common bile duct and in relation with the cystic duct A common hepatic of superior mesenteric origin *may actually bore through the head of the pancreas* and pass to its anterior surface where it simulates a gastroduodenal artery as observed by the author in one case (Fig 38) In another very odd case a replaced right hepatic of superior origin gave rise to the *middle colic* a bit distal to its own point of origin (Fig 36)

Two standard anatomic facts should always be borne in mind by the surgeon when dealing with a right hepatic that arises from the superior mesenteric *to wit (1) its upper portion* may give off the retroduodenal artery or the *superficial branch of the cystic artery* at times the entire cystic (Figs 84 90 82) (2) *its lower portion behind the pan*creas may receive the inferior pancreaticoduodenals of the anterior and the posterior pancreaticoduodenal arcades and in some instances gives rise to an important pancreatic artery viz the dorsal pancreatic or the transverse pancreatic artery (Figs 85 86)

For a further discussion of aberrant right hepatics arising from the superior mesenteric and their import in altering topographic relationships in the biliary region the reader is referred to Chapter 5

Accessory Middle Colic

The accessory middle colic is an additive vessel supplying the transverse colon occurs rather frequently Steward and Rankin *having observed an inci*dence of 10 per cent As a rule it arises *from the superior mesenteric above* the normal middle colic (Fig 42) In this study of 200 specimens it occurred on several occasions as a component of the supracolonic vessels i e it arose from the celiac trunk the first part of the hepatic or the splenic being actually an enlarged dorsal pancreatic prolonged into the transverse mesocolon (Fig 41)

In its descent *behind the splenic vein* the accessory middle colic of celiac axis origin gave rise *to the dorsal pancreatic* and the transverse pancreatic arteries then entered the transverse mesocolon where it coursed to the left and divided into two main branches an upper one

the long branches arising mostly from the latter, a few being given off by the marginal artery. They supply the proximal two thirds of the colon and accordingly afford the main blood supply. Because of the slight anastomoses of the terminal arteries and the perpendicular course which they take to the axis of the colon, Steward and Rankin suggest that greater care should be taken in handling and resecting the large intestine than the small intestine. When a surgeon is suddenly faced with a case of resection of the large intestine because of a tumorous condition discovered at laparotomy, it is important for him to know the distance of the marginal artery of Drummond from the wall of the colon. Anatomically considered, no definite spatial relations can be given, as conditions vary not only in every instance but also in different parts of the course of Drummond's artery—thus from a fraction of 1 to 10 cm. A point always to be remembered is that the marginal artery is farthest from the wall of the colon at points of bifurcation of the main arteries. As pointed out by Steward and Rankin, the larger the marginal artery is at any point, the more distant it is likely to be from the colon.

The surgeon's best guide in operative procedures in the upper abdominal region is to know and to realize that arterial variations are ubiquitous possibilities. Knowledge of these variations as depicted in this atlas and of how they are brought about affords the surgeon guidance and confidence and in most instances rewards him with successful operative results. Angulation of a vessel due to traction in the mobilization of an enteric segment, like the duodenum, the jejunum or the colon, should present no difficulties once the regional artery and its mode of distribution are known and have been checked purposefully.

The great poet and philosopher Goethe, in speaking of history, once said: He who cannot render an account to himself of at least three thousand years of time will always grope in the darkness of inexperience, and merely live from day to day (Panebaker's translation). This truism may well be applied to the asset of having a knowledge of the variational arterial patterns of the upper abdominal organs, although the number (3 000) need not be that high, for those selectively presented in this atlas are deemed sufficient to familiarize the anatomist and the surgeon with the major existent constitutional variations.

to furnish the necessary vasculature This holds true as a rule but there are many exceptions for in about 5 per cent the marginal artery is discontinuous *Weak points in the scalloped anastomotic arches* in the marginal artery are (1) between the ileocolic and the right colic between the middle colic and the superior left colic (3) between the inferior left colic and the superior hemorrhoidal arteries

Following *the work of Sudeck* (1907) and Monasse (1907) it was commonly believed that the marginal artery did not link up the lowest sigmoid artery (sigmoid ima) with the superior hemorrhoidal except in a few instances and then only in a precarious manner so that if the superior hemorrhoidal became obstructed beyond the origin of the lowest sigmoid there was little chance that a collateral circulation would be established—i e little blood would reach the vessels of the rectum

On the basis of this supposition Sudeck established a critical point on the inferior mesenteric artery i e a point above the origin of the last sigmoid as *the safest point for ligation to assure maintenance of an adequate* blood supply after mobilization of the rectosigmoid and the rectum It is interesting to note that Drummond (1914) failed to find an anastomosis between the marginal artery and the superior hemorrhoidal in 10 per cent of the cases while in 40 per cent it was negligible Reference to subsequent investigations on the validity of Sudeck's point has already been considered By injecting regional vessels with extreme care and consideration Greenberg (1950) was able to demonstrate that the lowest sigmoid (sigmoid ima) is anastomosed with adjacent sigmoid arteries to complete the marginal artery of Drummond in 81 per cent of 74 cases To obviate any dubious operative procedure Bacon and Smith and Torraca suggested that *transillumination of the mesentery at operation* is the final and best method of ascertaining the actual existent vascular pattern of blood supply between the rectosigmoid and the rectum

Vasa Recta of the Large and the Small Intestines

There remain for consideration existent differences between the vasa recta of the small as compared with those of the large intestine The mode of origin of the terminal colic arteries is considerably at variance with that of the intestinal arteries for the arcades are less numerous—i e they do not run in primary secondary tertiary quaternary or even in a network of quinary loops but largely are restricted to secondary scalloped loops with intermittent tertiary loops or arcades as the prevalent pattern

According to Steward and Rankin the terminal arteries arise independently *from the marginal artery and proceed* directly to the wall of the colon anastomoses between them being very rare They are most numerous in the cecum and the ascending colon Those of the transverse colon are smaller and fewer in number

The terminal arteries comprise two types short and long the two combined effecting the entire blood supply Near the mesocolonic taenia the long terminals divide one branch coursing in the haustra on the anterior the other on the posterior wall of the colon While coursing in the serosa they supply the epiploic appendages and give branches to the peritoneum before passing under the longitudinal muscles to reach the distal or amesocolonic surface of the colon *In elevating and clamping fat pads the long terminals may be injured readily* The short terminals are four to five times more numerous than

Three Collateral Pathways Inside the System of the Splenic Artery

They comprise (1) a widespread (30 per cent) system of outer and inner hilar transverse anastomoses between the lienal branches These represent the final communication between the latter for distal to the inner hilar transversals the intra organic lienal branches terminate as end arteries (Figs 148–151) (2) A short transpancreatic route effected by the a caudae pancreatis (branch of the splenic or the left gastro epiploic) communicating with the a pancreatica magna given off by the splenic in its distal third portion or with the dorsal pancreatic when the latter arises from the splenic (Figs 111 113 131) (3) A short anastomosis in a tortuous loop of the splenic trunk i e when different portions of a looped section of the splenic artery or two early divisions of the artery are connected by a short anastomosis (Fig 116)

Twelve Collateral Pathways Outside the System of the Splenic Artery

They are effected by regional neighboring arteries other than those of the splenic communicating with the splenic or its branches This outside system of collaterals is so widespread that it may replace the entire system of the splenic artery The most important routes are

1 **Arcus Arteriosus Ventriculi Inferior of Hyrtl** This infragastric epiploic (omental) pathway is situated in the anterior two layers of the great omentum and is made by the right and the left gastro epiploics as they anastomose along the greater curvature of the stomach (Fig 50) The anastomosis may be effected as main vessels or in the form of a network of arterioles and capillaries for the left gastro epiploic often falls short of full anastomosis (10 per cent) (Fig 60) The arc gives off short ascending branches to the anterior and the posterior surfaces of the stomach and short and long branches (omental epiploic) to the great omentum (Fig 100)

2 **Arcus Arteriosus Ventriculi Superior** This (supragastric) omental pathway along the lesser curvature is made by the anastomosis of the right gastric and the left gastric (Fig 61) Branches of the left gastric anastomose with the short gastrics from the splenic terminals and the left gastro-epiploic or with branches from the left inferior phrenic (Fig 100) Branches of the right gastric may unite with branches from the gastroduodenal the supraduodenal the retroduodenal the superior pancreatico duodenal or the right gastro epiploic (Fig 51) The arc gives off descending anterior and posterior gastric branches To the left it may be associated with the blood supply of the esophagus and the liver via an aberrant left hepatic from the left gastric to the right it may contribute to the blood supply of the duodenum (Fig 100)

3 **Arcus Epiploicus Magnus of Barkow (1793)** This important infracolonic epiploic omental pathway is situated in the posterior layer of the great omentum 2 to 4 cm below the transverse colon The left limb of the arc is invariably formed by the left epiploic derived from the left gastro epiploic The right limb of the arc is made by the right epiploic derived from the right gastro epiploic The supply arteries in this collateral route comprise the hepatic the gastroduodenal the right gastro epiploic the right epiploic the left epiploic the left gastro epiploic the inferior terminal of the splenic (Figs 1 2 100)

The right limb of the arc may unite with the first or the second anterior epiploic from the right gastro epiploic or with a posterior epiploic derived from the transverse pancreatic or the dorsal pancreatic The arc receives several an

You cut only what you see; as a corollary, do not cut until you do see.

—JOHN B. DEAVER

13

Routes of Collateral Circulation in the Upper Abdominal Organs

Categorization of Collateral Pathways on an Anatomic Basis

In view of the innumerable variations in the vascularization patterns of the liver, the pancreas, the stomach and the spleen, a precise categorization of collateral pathways for the upper abdominal organs is extremely difficult. Textbooks do not mention the collateral circulation of the supramesocolonic organs, yet it is quite obvious that no other region in the body presents more diversified routes of blood supply to a specific organ than is the case with the organs lying above the transverse colon. Because of the large quantity and the loose arrangement of its connective tissue, and the abundance of its blood vessels, the great omentum is exceptionally well adapted to function as a seat of compensatory collateral circulation for both the liver and the spleen—i.e., when either the hepatic or the splenic artery *is occluded*.

The pancreas lies in three interlocking arterial circles formed by the hepatic, the splenic and the superior mesenteric, none of which is the sole blood supply to the organ. Part of the blood supply to the liver may come from the celiac artery (only a right or only a left hepatic); part of it may come from the superior mesenteric (accessory or replaced right hepatic). A liver may have three separate sources of blood supply, to wit: right, middle and left hepatics from the celiac; an accessory left hepatic from the left gastric; an accessory right hepatic from the superior mesenteric—a total of five supplying arteries (Fig. 16).

The stomach receives its main blood supply from five different sources: (1) a left gastric from the celiac; (2) a right gastric derived from the right or left hepatic, the hepatic or the gastroduodenal; (3) a right and a left gastroepiploic, respectively derived from the gastroduodenal and the splenic; (4) a series of short gastrics or fundic branches from the splenic; (5) esophageal and fundic branches from the recurrent branch of the left inferior phrenic (Figs. 47, 49).

Because of the cited relational anatomy, it is quite obvious that the collateral pathways for the upper abdominal *organs are effected mainly* by the splenic artery. Splenic collateral pathways comprise two types: (1) those which are short and are effected by splenic branches communicating with themselves, i.e., they occur within the branches of the splenic arterial system; (2) those which are long and which occur outside the splenic system, i.e., in branches not directly related to the splenic artery.

from an accessory left gastric coursing posteriorly along the fundic region of the stomach, and arising from the splenic the superior polar artery of the splenic, or the celiac (Figs 50 60 51)

9 Circulus Hepatolienalis Accessorius Here an accessory or a replaced right hepatic or even the entire hepatic derived from the superior mesenteric and passing behind or through the head of the pancreas may be connected with the splenic via a branch of the dorsal pancreatic or the gastroduodenal derived from the splenic or via the transverse pancreatic and the a caudae pancreatis when such connection is made (Figs 86 38 53)

10 Circulus Celiacomesentericus The three most common routes for this pathway are (1) Via a direct longitudinal communication between the splenic or the hepatic and the superior mesenteric when the dorsal pancreatic of splenic or hepatic origin descends beyond the inferior border of the pancreas to unite with the superior mesenteric the middle colic or an accessory middle colic (Figs 39 60 41) Commonly known as the artery of Riolan the accessory middle colic often ramifies in the left third of the transverse mesocolon before reaching the transverse colon which it supplies One of its branches unites with the left branch of the middle colic the other with the ascending branch of the left colic (2) The superior mesenteric artery may be linked longitudinally to the celiac by a solitary large (1 to 2 mm) anastomotic vessel the ramus anastomoticus of Buhler coursing behind the pancreas (Fig 29) (3) Blood may be routed from the superior mesenteric through the inferior pancreaticoduodenal then through the anterior and the posterior pancreaticoduodenal arcades to reach the gastroduodenal from which via the right and the left gastro epiploics it reaches the splenic or via the common hepatic it reaches the celiac (Figs 18 50)

11 Circulus Gastrolienophrenicus This collateral pathway may be effected in two ways (a) via a direct communication between the short gastrics or an accessory left gastric from the splenic and the recurrent branch of the left inferior phrenic on the back of the cardio esophageal region of the stomach (Fig 67) (b) via a direct communication between the cardio esophageal branches of the left inferior phrenic and the cardio esophageal branches stemming from the left gastric directly or via its aberrant left hepatic branch or stemming from an accessory left gastric derived from the left hepatic (Figs 59 63)

12 Circulus Bifurcatus Here the blood supply to the upper abdominal organs is completely split one half coming from a hepatic arising separately from the aorta and giving rise to the gastroduodenal the other half coming from a lienogastric trunk (Fig 66) Collateral pathways between the two systems are effected by an anastomosis of the terminal branches of the right and the left hepatics and by communications variously routed through the pancreatic the gastric and the omental circles

Numerous other collateral pathways involving branches of the splenic artery could be outlined—e g a direct communication between the gastroduodenal or the retroduodenal and the splenic when a branch of either the former arteries unites with the dorsal pancreatic or with the a pancreatica magna of splenic origin (Fig 75) Of all the listed collateral pathways those made available through the arcus epiploicus magnus of Barkow situated below the transverse colon on the posterior wall of the great omentum are the most effective and widespread (Fig 100) Because of its position in the loose readily expandable and highly vascularized con

terior epiploic arteries which after their origin from the right and the left gastro epiploics descend in the anterior layer of the great omentum to its free distal border then ascend in the posterior layer to join the arc Some of the ascending *posterior epiploic arteries* arising from the arc supply the transverse colon others unite with the descending posterior epiploic arteries derived from the transverse pancreatic artery coursing along the inferior (caudodorsal) surface of the pancreas (Fig 100)

4 Circulus **Transpancreaticus Longus** This important collateral pathway is routed through the entire length of the pancreas and is effected by the a caudae pancreatis (end branch of the splenic its terminals or the left gastro epiploic) uniting with the transverse pancreatic artery *coursing along the inferior sur*face of the pancreas To the right the transverse pancreatic may communicate with the hepatic in the event it arises from the gastroduodenal the superior pancreaticoduodenal or the right gastro epiploic or it may communicate with the superior mesenteric in cases where it takes origin from this vessel or from an accessory middle colic (Fig 100)

A transverse pancreatic artery arising *from the superior mesenteric may be* sufficiently large to constitute a second splenic artery (a splenica secunda Fig 121) Via the dorsal pancreatic of which it is predominantly the major left branch the transverse pancreatic may communicate with the splenic the hepatic or the celiac depending on which artery gives rise to the dorsal pancreatic When the transverse pancreatic arises from the superior mesenteric a *collateral pathway* is established which will function when either the hepatic or the splenic is occluded (Fig 62) Arteries involved in the hepatic transpancreatic route are *the hepatic the gastro* duodenal the superior pancreaticoduodenal the transverse pancreatic the a caudae pancreatis the inferior terminal of the splenic (Fig 100) Arteries involved in the *superior mesenteric* transpancreatic route are the superior mesenteric the transverse pancreatic the a caudae pancreatis, the inferior terminal of the splenic (Fig 100)

5 Circulus Pancreaticoduodenalis This collateral pathway occurs outside the channel of the transverse pancreatic artery and is composed of multiple and devious routes Various branches of the gastroduodenal and the superior and *the inferior pancreaticoduodenals ulti*mately unite with branches of the splenic, notably with those of the dorsal pancreatic the a pancreatica magna and the a caudae pancreatis (Figs 52 62)

6 Circulus Coronarius Inferior In this pathway collaterals of the short *gastrics from the superior* and the inferior terminals of the splenic unite with branches of the arcus arteriosus ventriculi inferior (Fig 51)

7 Circulus Hepatogastricus Developmentally considered this is the primitive arched anastomosis of Piquand (1910) between the left gastric and the left hepatic situated at the left peripheral edge of the lesser omentum The arc may persist in its entirety (4 per cent) (Fig 53) *If the lower half* is lost the upper becomes an accessory left gastric (3 per cent) (Fig 65) In one fourth of the population the lower half persists and becomes either an *accessory* or a replaced left hepatic (Figs 49 76) Cardio esophageal branches stemming from the arc or from the respective vessels derived from it communicate with the cardio esophageal branches from the left gastric short gastrics from the splenic and the left gastro epiploic and from the recurrent branch of the left inferior phrenic (Fig 100)

8 Circulus Gastrolienalis Accessorius In *this pathway short gastrics* from the superior and the inferior terminals of the splenic artery unite with branches

middle colic is inadvertently injured or tied off or an accessory middle colic (10 per cent Steward and Rankin) is overlooked and sacrificed

10 A surprising necrosis and gangrene of the first part of the jejunum when this part of the small bowel is deprived of its blood supply as is apt to happen in many instances when the jejunal arteries (1 to 3) which supply it are not derived directly from the superior mesenteric but spring from the pancreaticoduodenal arcade and then cross to the left under the superior mesenteric (Figs 70 81 93 95)

Experienced and conservative surgeons know full well that in abdominal surgery the treatment of major arteries should never be light or indifferent for the penalty of dalliance may be disconcertingly severe viz irreparable necrosis and gangrene As recently emphasized by Giles (1953) in his article on Surgical Diseases of the Biliary Tract the dictum of John B Deaver is still the best guide at operation You cut only what you see as a corollary do not cut until you do see

In a discussion of the author s Variational Anatomy of the Hepatic Cystic and Retroduodenal Arteries [1] Dr Warren H Cole of Chicago made the following comment

I should like to emphasize one point he made namely that the anatomy of the biliary tract is different in every person If one damages the hepatic artery and ligates it death will ensue in about one half of the patients One should never rely upon one s knowledge of anatomy when dissecting in this region because of frequent anomalies one must use one s eyes be very careful and not be in a hurry when dissecting in this area *

In regard to the dual cystic arteries (25 per cent) he said

The danger is that the surgeon will see and ligate one cystic artery and then proceed so rapidly with dissection that the second artery is cut with production of a hemorrhage which may be difficult to control This accessory cystic artery usually arises from the hepatic artery just beneath the common duct after severance it retracts posterior to the common duct and blind stabbing with an instrument by the surgeon may result in obstruction of the common duct as the bleeding point is ligated *

As regards the artery running parallel with the cystic duct he said

time and time again I have been ready to put a clamp on this artery parallel to the cystic duct only to discover after another investigation that it was the right hepatic I am sure that every surgeon has had that experience at some time or other *

Dr I S Ravdin of Philadelphia made the following comment on the paper

While most surgeons teach that cholecystic surgery is easy it is difficult Those who think they have ligated the hepatic artery frequently have not ligated the whole arterial supply to the liver The only way to avoid injury to the common duct during cholecystectomy is accurately to visualize the junction of the common and the cystic ducts *

The Postcholecystectomy Syndrome (Hepatorenal Syndrome)

Behrend (1920) Gordon Taylor (1943) Vaughn (1946) Gray (1951) Glauser (1953) Sven Ramstrom (1953) and many others are of the definite opinion that many of the so called liver deaths after removal of the gall bladder may well be due to a clamping or ligation of the hepatic artery or of its right hepatic branch or of an anomalous branch thereof

Unpalatable indeed is the categorization made by the British surgeon Gordon Taylor (1943) viz that

1 Presented before the Section on Surgery General and Abdominal at the 101st Annual Session of the American Medical Association Chicago June 11 1952

* *Arch Surg* 66 20 1953

nective tissue of the great omentum, *this infracolic arc serves as an excellent* compensatory pathway not only for the spleen but also for the liver, the stomach and the pancreas. The large epiploic arc and its many *variants are described* more fully in the chapter on the blood supply of the great omentum (Chapter 11).

Ten Examples of Operatively Induced Devascularization

As a surgical precaution and as an anatomic *admonition, it should always* be borne in mind that the cited collateral pathways are only possible, at most probable routes. They cannot be relied upon to re-establish an adequate compensatory viable circulation in all cases when an important regional artery has been severed. The fact that many or most individuals have survived in an operative procedure where an important artery has been sacrificed is counterbalanced by the sad and distressing fact that, as a direct sequence to routine unstudied ligation or inadvertent injury of a main artery, many patients after the operation (especially cholecystectomy) have suffered agonizing pain and have been exposed to weeks and months of worry, while others have died as a direct result of an operatively induced ischemic necrosis in a life-sustaining *organ, as evidenced in postmortem* examinations.

Among the striking examples of the effects of operatively induced devascularization and exsanguinization the following are the most noteworthy:

1. Ischemic necrosis of the right or the left lobe of the liver as a result of inadvertently cutting, respectively considered, the right hepatic or *one of its* anomalous branches in the search for the cystic or an aberrant left hepatic from the left gastric in gastric resections (Ritter, 1922).

2. Distressing hemorrhage in a case with a double cystic (25 per cent) when one is ligated and the other is cut with subsequent retraction of the latter behind the common duct (Cole, 1953).

3. *Devascularization* of the lower esophagus when the left gastric is cut to facilitate gastric mobilization (Shapiro and Robillard, 1950).

4. *Necrosis* and *perforation of the* stomach wall by cutting the left gastro-epiploic too short or by not sparing the short gastrics (Henschen, 1928). In the 200 dissections made by the author the right and the left gastro-epiploics failed to anastomose in 10 per cent.

5. Fatal hemorrhage following splenectomy by not taking note of a long slender superior polar artery to the spleen arising from the first part of the splenic or from the celiac axis (William Mayo, 1908).

6. *Necrosis of the pancreatic tail* by including a part of it in the ligature in splenectomy. Postoperative hemorrhage, pancreatitis, fat necrosis, cyst formation and fistularization when important pancreatic rami of the splenic are tied (Henschen, 1928).

7. Fatal ischemic diastasis of the suture lines due to an inadequate blood supply in esophago-gastrojejunostomies (Shapiro and Robillard, 1950). Anatomically considered, a blow-out of the duodenal stump may be due in some *instances to an inadequate blood supply* caused by excessive stripping of the areolar tissue on the back wall of the duodenum, the tissue containing the retroduodenal blood supply made by the retroduodenal artery.

8. Necrosis of the common bile duct due to a severance of its blood supply coming from branches of the supraduodenal artery of *Wilkie* and the retroduodenal artery (Appleby, 1953—personal communication).

9. Necrosis of the colon from the lienal flexure to the sigmoid when the

Peritoneal Absorption

A major unsolved problem is the role played by the peritoneum in the removal i e the absorption of foreign material and fluid from the peritoneal cavity Diverse studies on normal pathologic and experimental material have shown that in mammals the omentum plays an important role in peritoneal absorption (Haller 1764 Maffucci 1882 Heidenhein 1891 Eccles 1894 Cohnstein 1895 Durham 1897 Buxton and Torrey 1906 Rose 1907 Rubin 1911 Dandy and Rowntree 1914 Crouse 1915 Shipley and Cunningham 1916 Hertzler 1919 Crissan 1928 Higgins and Bain 1930 and Webb 1931 of Indiana University)

A second factor in the mechanism of peritoneal absorption is the diaphragm as ascertained by von Recklinghausen (1862) Auspitz (1871) Dubar and Remy (1882) Maffucci (1882) Orlow (1894) Muscatello (1895) MacCallum (1903) Buxton and Torrey (1906) Rose (1907) Bolton (1921) and Cunningham (1922) According to Bolton absorption of foreign fluid is accomplished solely by the diaphragmatic lymphatics while MacCallum Buxton and Torrey regard them to be the most important factors

That the mesentery actively participates in serous absorption was shown by Maffucci (1882) Shipley and Cunningham (1917) Crissan (1928) and many others While uncertainty still exists as to the paths whereby fluid from the peritoneal cavity enters into the vascular system the following pathways of peritoneal absorption have been advocated (1) lymphatics (2) blood vessels (3) stigmata stomata or serous openings von Mollendorff (1927) (4) ubiquitous intracellular absorption into subserous lymphatics and blood capillaries As far as inert particulate matter is concerned various investigations have shown that much of it is removed from the peritoneal cavity by polymorphonuclear leukocytes and wandering phagocytes many of the latter being of local connective tissue origin including fibrocytes and *mesothelial cells (von Mollendorff 1927* Michels 1933)

Interested in the problem of peritoneal absorption from a phylogenetic point of view Mackmull and the author (at the Daniel Baugh Institute of Anatomy) investigated the peritoneal absorption of colloidal carbon that had been injected into the coelomic cavity of the marine teleost the cunner (*Tautogolabrus adspersus*) by Dr Mackmull at Woods Hole Biological Station in 1930

Among the observations reported by Mackmull and Michels along with the pertaining literature up to 1931 the following are the most important In the cunner intraperitoneally injected carbon reached various organs and tissues (a) as free ink granules (b) by direct infiltration of carbon filled cells—i e macrophages derived from the peritoneal cavity—and (c) by migration of carbon filled macrophages from vascular channels Direct absorption of free carbon particles from the peritoneal cavity was accomplished chiefly by the mesentery and the intestine One hour after injection the vascular channels transported free carbon particles and carbon macrophages to all organs investigated (heart gills spleen intestine testis ovary kidney) Direct (i e nonvascular) infiltration of carbon macrophages from the coelomic cavity occurred in the intestine the mesentery the gonads and occasionally the liver The reticulo endothelial cells in the spleen liver kidney and heart were intensely phagocytic and cytopoietic In this connection it should be noted that Grissan (1928) appended the *abdominal serosa* as an integral portion of the reticulo endothelial system Research here is needed

It is highly probable that many cholecystectomies performed by amateurs in which grave morbidity or death ensues owe their *unfavorable course to an unfortunate inclusion of the right branch of the hepatic artery in a clamp or a mass ligature of the cystic duct and the contiguous artery (Brit M J 1 501 1913)*

Not less palatable is *the conclusion* recently arrived at by Sven Ramstrom of the Faculty of Medicine Gothenburg Sweden (*1953*) to wit

> Certain obscure deaths after apparently *uncomplicated biliary operation* could well be due to unintentional ligation of an anomalous branch of the hepatic artery

After a four year study (anatomic and experimental) Ramstrom maintains that *hepatic lesions of all kinds* (toxic infectious and post traumatic) influence renal function impairing it and causing renal failure even though the kidneys are normal This interplay between liver injury and renal insufficiency is known as the hepatorenal syndrome and a necrosis of part of the liver induced by severance of a liver artery may well result in renal insufficiency

Ramstrom s *conclusion is in accord* with that drawn independently by Glauser (1953) in a roentgenographic study of injected liver arteries made under the supervision of Dr Ravdin and Dr Batson of the University of Pennsylvania Drs Healey and Schroy in a study of the intrahepatic vascularization patterns rendered visible in 100 plastic corrosion casts made at the Daniel Baugh Institute of Anatomy of Jefferson Medical College concluded that

> ligation of a segment artery will result in complete deprivation of arterial blood to the segment of hepatic parenchyme which it supplies

Approaching *the problem* from another angle Giles (1953) maintains *that the so called postcholecystectomy* syndrome may be due to (1) stones left in the common duct (2) too long a cystic duct, as reported by Womack and Garlock (3) injuries to the common duct (4) operations for noncalculous cholecystitis (5) biliary fistulas (6) spasm of the sphincter of Oddi (*according to Doubilet and Mullholland*)

In speaking of surgical injuries to the bile ducts Flint, of England (1923) stated that Surgeons are ashamed of committing such errors and rightly so and do not feel disposed to advertise them The same is true of operatively induced injuries to major blood vessels The *inclusion of such vascular injuries* in the postmortem records of individuals dying after resection of one or more of the upper abdominal organs *is highly* desirable but deplorably unavailable in most instances no study of this anatomic phase of the problem usually being made

Since the primary purpose of the author in this descriptive atlas is to advance anatomy to a stage where arterial *variations can be defined* in common denominators and appreciatively apprehended for surgical *consideration* and use the correlation of mortality rate to fatal vascular injuries in major abdominal operations is a problem awaiting dire solution by the pathologist His is the judicially important third step *to be taken in a combined* anatomico pathologic statistical estimate of surgical failures which thanks to newer anatomic knowledge and a *higher* regard and application of it in surgical training and surgical practice are decidedly less frequent today than years ago

A knowledge of the variational arterial patterns of the upper abdominal organs selectively presented in this atlas is deemed sufficient to familiarize the anatomist and the surgeon with major existent constitutional variations

according to Kelty et al being the result of the *regenerative nodule*. The central veins into which the sinusoids flow are not normal and are forced toward the perilobular connective tissue surrounding the regenerative nodule the dynamic and expansive force of which according to Kelty et al is more important in the production of distortion tortuosity narrowing of the lumen and obliteration of the vascular tree than the increase of the fibrous tissue. The hepatic parenchymatous cells are divorced from their normal portal blood supply and ultimately become nourished almost entirely by the hepatic artery which by virtue of its much higher head of pressure remains intact for a longer period than the vein.

If the integrity of the regenerative parenchymatous tissue in the cirrhotic liver is dependent on its arterial blood supply and if hepatic failure is primarily a result of intrahepatic vascular insufficiency (McIndoe) it would seem that the ligation of the hepatic artery is a paradoxical phenomenon in that it deprives the rapidly growing parenchymatous tissue of its blood supply unless a compensatory arterial circulation quickly can be established by collateral pathways.

Review of the Literature

Simon de Metz is cited by Narath (1916) as the first to have ligated the hepatic artery having done this in doves in 1828. Haberer of Germany (1905) showed most conclusively that when the hepatic artery was ligated distal to the origin of the right gastric in dogs cats and rabbits the animal *invariably* died of liver necrosis within 1 to 3 days after operation. He further showed that the danger of liver impairment increased as ligation was made *nearer the liver* and that ligature of the right or the left hepatic in rabbits resulted in a necrosis of the respective lobe supplied by these vessels. Numerous and diversely executed have been the subsequent animal experimentations confirming the fact that ligation of the hepatic is followed by extensive necrosis of the liver appearing within 12 hours and rapidly extending throughout the organ with invariably fatal issue. While liver cells die if they are deprived of arterial blood lack of portal blood does not produce anemic necrosis furthermore the parenchymatous liver cells can *use* arterial blood in the portal vein as ascertained by Narath (1916) in a series of arterio-portal anastomoses in dogs.

Extensive reviews of the literature pertaining to the ligation of the hepatic artery have been compiled by Haberer (1905) Narath (1916) Ritter (1922) Cameron and Mayes (1930) Graham and Cannell (1933) and most recently by Markowitz and Rappaport (1951) and by the author in his article published in *Cancer* 6 708–724 1953 it being a sequel to Appleby's paper on the removal of the celiac axis in the expansion of the operation for gastric carcinoma.

Ligation of the Hepatic Artery in Animals

Haberer of Germany (1905) was the first to show that when the common hepatic was ligated in dogs proximal to the origin of the gastroduodenal the arterial supply to the liver was not diminished markedly for the intact hepatic artery distal to the ligature received a collateral blood supply via the gastroduodenal and the superior mesenteric. More recently Cameron and Mayes (1930) of England came to the same conclusion in experiments with rabbits. A ligation of the hepatic artery proximal to the origin of the gastroduodenal resulted in no liver damage but a ligation of the artery beyond the gastroduodenal was immediately followed by extensive necrosis of the liver

Enter his chamber view his breathless corpse and comment then upon his sudden death

—WILLIAM SHAKESPEARE Henry VI

14

Collateral Arterial Pathways to the Liver After Ligation of the Hepatic Artery and Removal of the Celiac Axis

Introduction

Strikingly unprecedented innovations in surgery are the ligation of the hepatic artery for portal cirrhosis (Rienhoff) and the complete removal of the celiac axis and the gastric bed of lymphatics lymph nodes and organs en bloc for carcinoma of the stomach after the integrity of the superior mesenteric artery previously had been established (Appleby) Survival of patients after these seemingly drastic operative procedures is startling for all surgeons are mindful of the fact that from the beginning of their training in anatomy and surgery they were taught not to interfere with the blood supply of the liver the hepatic being the *one* artery in the opinion of innumerable reputable surgeons that could never be ligated under any condition This axiomatic principle was based on many years of animal experimentation and surgical experience

That some kind of compensatory collateral circulation to the liver was established in individuals who survived the respective operations is quite obvious although its nature extent and degree of effective duration are as yet largely unknown *Since no mention is made in textbooks of anatomy or surgery of collateral arterial pathways to the liver* the following detailed account of possible arterial routes to the liver parenchyma as ascertained in 200 dissections of human bodies may afford the *anatomic rationale* of survival after the common hepatic or the celiac trunk has been divided

For orientation purposes of this very important topic of a ligature of the hepatic artery in portal hypertension the following items on cirrhosis of the liver are worthy of note and consideration For many years it has been known that the hepatic artery has a peculiar functional and regional distribution in cirrhosis of the liver This was shown in particular by McIndoe (1928) in his studies of vascular lesions of portal cirrhosis as observed by the injection *maceration technic* by Dock (1942) in his studies of increased hepatic arterial blood flow in portal hypertension by perfusion methods and by Kelty Baggenstoss and Butt (1950) in their study of regenerative nodules as seen in a wax model reconstruction made at the Mayo Clinic

These authors have shown that in cirrhosis *there is a marked diminution* in the total intrahepatic vascular bed caused by the contraction of fibrous tissue and that ultimately hepatic failure is due to *intrahepatic vascular insufficiency* (McIndoe) venous obstruction

ment is shown by liver function tests.

Previous to the latter investigators, Tanturi, Swigart and Canepa (1950) of Northwestern University reported that ligation of the hepatic proper arteries (1 to 5) in 32 dogs produced a mortality of 68.7 per cent. Death occurred from 17 hours to 4 days postoperatively, the average survival time being 37 hours. Postmortem studies revealed necrosis and infarcts in the liver and the presence of a lecithin-splitting enzyme (lecithinase) in the abdominal fluid. The enzyme was identified with the alpha toxin of *Clostridium perfringens* type A, an organism whose properties appear to correlate well with the ability to produce this toxin. Penicillin treatment prevented death by inhibiting the growth and the proliferation of anaerobic bacteria and the production of the lethal enzyme in 8 dogs (100 per cent). In 10 dogs (31.3 per cent) that survived, no arterial collateral circulation was found to account for the survival, the small vessels observed in the hepatoduodenal ligament being regarded as insufficient to carry a vital supply. Authors noted that when the hepatic proper arteries were ligated but not severed, a recanalization of them occurred in a later postoperative period. Injections of red lead into the hepatic arteries of normal dogs failed to demonstrate a subcapsular anastomosis beneath Glisson's capsule or any communication with the inferior phrenics in the coronary and the falciform ligaments.

Significant indeed is the fact that Jefferson, Proffitt and Necheles (1952) in surgical experiments with 36 dogs noted that complete occlusion of the hepatic artery can be effected only by complete excision of the hepatic arterial trunk. When an adequate collateral circulation from the phrenic arteries was established, some dogs survived without antibiotics after complete hepatic arterial excision. The collateral circulation was effected by the left and the right inferior phrenic and the right superior phrenic arteries. On no occasion was there any evidence that a collateral supply to the liver came from the upper branches of the left gastric, the left superior phrenic or the esophageal arteries.

A most disparaging view on ligations of the hepatic artery is taken by Sven Ramstrom of the Faculty of Medicine, Gothenburg, Sweden (1953). After a four-year study (anatomic and experimental) he maintains that traumatic necrosis of the liver due to severance of a hepatic artery is *definitely associated with renal dysfunction (uremic disturbance, hepatorenal syndrome)*. After ligating a large branch of the right hepatic distally of the right gastric in rabbits, the animals recovered from the operation, but all died in 17 days, the mean survival time being 7 to 8 days. The extent of the liver necrosis varied from 10 to 80 per cent of the liver parenchyma and the animals died without showing elevations in nonprotein nitrogen level.

In contrast with these negative results are the following observations. Berman, Koenig and Miller (1951) in experiments with portal hypertension in dogs showed that (1) ligation of the hepatic artery at the celiac axis caused a fall in portal pressure of 10 to 20 mm. of water; (2) ligation of the splenic artery after ligation of the hepatic caused an additional fall of 40 to 50 mm. of water. Accordingly, the authors concluded that ligation of the splenic and the hepatic produced a sustained fall of portal pressure. Witter and First (1953) in experiments with dogs (in which the left gastric was divided 2 cm. from the axis and a reading made, and in which the hepatic and the splenic were occluded with clamps and a second reading made) concluded that the small rise in blood pressure in the left gastric artery following

and death of the animal within 1 to 6 days after operation Huggins and Post (1937) likewise confirmed the fact that ligation of the hepatic artery and its largest collaterals the gastroduodenal and the right gastric in one stage was always fatal in dogs death being due to liver autolysis and occurring within 72 hours If, however the arterial circulation was gradually reduced by ligations made at multiple stages (first the hepatic proximal to the gastroduodenal 1 to 4 weeks later the gastroduodenal or the right gastric) death from anaerobic bacteria did not take place and the liver became accommodated to deprivation of most of its arterial blood Liverato Vagliano and Dervenagra (1935) had likewise noted that when the hepatic artery is removed in stages the final complete privation of arterial blood does not influence the life of the animal Loeffler (1936) was among the first to show that the liver of rats and rabbits can survive on portal venous blood alone

It is interesting to note that in an investigation made at the Daniel Baugh Institute of Anatomy of Jefferson Medical College *as early as 1922* Behrend Radasch and Kershner were able to prove that animals showed a varied susceptibility to the effects of ligation of the hepatic artery depending on the point of ligation—i e whether it was made centrally or peripherally While rabbits and guinea pigs always succumbed to peripheral ligation dogs and cats resisted ligation and continued to live indefinitely In *all* animals however ligation of the hepatic artery resulted in a widespread degeneration of liver cells as repeatedly emphasized to his students by J Parsons Schaeffer Director of the Anatomical Institute at that time

New interest in the problem of ligation of the hepatic artery came with the report of Ellis and Dragstedt (1930) that gas gangrene produced by the ligation of the hepatic arterial supply was due to a diminution of the oxygen supply of the liver this condition allowing for growth of anaerobic organisms normally present in adult animals Markowitz Rappaport and Scott (1949) thereupon showed that dogs would *not* die after ligature of the hepatic if treated postoperatively with parenteral doses of penicillin the antibiotic action of the latter in their opinion preventing the growth of bacteria (cf Wolbach and Saiki 1909) which in untreated animals was the supposed cause of death Grant Fitts and Ravdin of the University of Pennsylvania (1950) confirmed this observation and noted that chlortetracycline (Aureomycin) given parenterally to dogs was just as effective Their untreated dogs died within 48 hours after ligation of the hepatic artery and showed massive hepatic necrosis

That ligation of the hepatic artery is not without danger and is followed by ischemic necrosis and death even in dogs treated with penicillin was shown by Grindley Mann and Bollmann of the University of Minnesota (1951) These authors reported that in their experiments all dogs were sick for a time and that their behavior and the development of jaundice by the sickest dogs pointed to impaired hepatic function or complete hepatic failure In their operative procedures they noted that arterial blood could be prevented from entering the liver at its hilus only when the hepatic branches were ligated close to the hepatic hilus A similar conclusion was arrived at by Fraser Rappaport Vuylsteke and Colwell (1951) in experiments of dogs in which the hepatic artery was ligated and antibiotic treatment administered They obtained a mortality rate of 35 per cent In the dogs that died there was ischemic necrosis of the liver in those that survived there was some degree of liver impair

ment is shown by liver function tests

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occlusion of the hepatic and the splenic is significant and may account for esophageal hemorrhage and that portal pressure may be markedly reduced by ligation of the splenic and the hepatic arteries

In an evaluation of the surgical results with the experimental ligature of the hepatic artery in dogs and applications thereof to man it is extremely important to know that the *biologic condition of the dog s liver is far different from that of the human liver* Most recently Brunschwig of the Memorial Center for Cancer and Allied Diseases New York (1953) maintains that while the liver of the dog is heavily infected with pathogenic anaerobes the human liver has proved to be sterile (Romieu and Brunschwig 1951) As a sequence to this Brunschwig (1953) concluded that any infectious process that may evolve after operation must be ascribed to exogenous sources

Ligation of the Hepatic Artery in Man

Previous to current surgical procedures clinical experiences with the purposeful ligation of the hepatic artery have been relatively few this fact being due to the disastrous results observed in animal experimentation Hans Kehr of Halberstadt Germany (1903) Europe s outstanding specialist on gall bladder surgery who visited the Mayo brothers in 1903 is the first to have successfully ligated the arteria hepatica propria distal to the point of origin of the gastroduodenal in a patient with aneurysm of the right hepatic artery A comparable ligation with successful cure was made by Sudeck (1919) and by Colmers (1921) for intrahepatic aneurysm Most recently Grant Fitts and Ravdin (1950) ligated the hepatic artery in two patients in whom hepatic aneurysm was diagnosed at operation but both died one from massive hepatic necrosis (despite treatment with streptomycin and penicillin) the other from recurrent hemorrhage In 1920 Behrend tried to save the life of a 12 year old boy who had been run over by a wagon with a resultant severance of the hepatic artery He tied both ends of the severed hepatic but the boy died Concerned as to whether ligation of the hepatic artery was responsible for the death Behrend thereupon investigated ligations of hepatic arteries in animals having at his disposal the advice and the opinion of Dr J Parsons Schaeffer then Director of the Daniel Baugh Institute of Anatomy of Jefferson Medical College

Surgical experiences with an accidental severance or ligation of the hepatic artery or one of its branches on the other hand have been many although in proportion to the mistakes that inadvertently have been made for obvious reasons relatively few have been reported in the literature Graham and Cannell of the University of Toronto Canada (1933) reported a case of a 49 year old man in whom the hepatic artery was accidentally ligated during a partial gastrectomy this fact having been ascertained following closure of the duodenal stump Although the patient became ill on the fourth day and died on the seventh day they were of the opinion that death was not due to liver insufficiency for only a relatively small amount of liver necrosis was observed at autopsy and a collateral circulation had apparently been established through the phrenic arteries and their diaphragmatic anastomoses

From a review of the 27 cases reported in the literature in which the hepatic artery or one of its branches had purposefully or accidentally been ligated and on the basis of their own case Graham and Cannell (1933) concluded that ligation of the hepatic artery is always a serious but not necessarily a fatal accident An analysis of their re

view (which contains the references to the authors cited—and in some instances corrected—below) shows the following effects of surgical interferences with the blood supply of the liver

Death within a few hours days or weeks following ligation of the common hepatic or of the hepatic proper arteries Socin and Rauch Salzer Sprengel Tuffier Wendel Behrend Graham and Cannell
Recovery Ritter Kehr (2 cases) Hofmeister Bakes Smith

Death after ligation of the right hepatic especially during a gastric resection Tichow Kausch Ritter Hofmeister
Recovery Allessandri Bertram Wendel Ritter

Death after ligation of the left hepatic during resection of the stomach Hofmeister (seventh day) Wilmer (sixteenth day) Gaube and Herrenschmidt Klose Holst
Recovery Pallicio Ranam Haberer

In summary then death resulted in 16 of the 28 cases cited (57 per cent) in which the hepatic or its branches had been ligated Authors stated that the role played by the resulting liver necrosis in these deaths was not easy to determine but at least in 7 cases death was attributable to liver insufficiency Kehr s case of recovery after ligation of the hepatic showed liver necrosis Wendel s case of ligature of the common hepatic had hemorrhagic infarcts and nearly total necrosis of the liver Tichow s case of ligature of the right hepatic presented a liver necrosis that extended to within 3 cm of the fissure between the lobes Ritter s case of a right hepatic ligation showed necrosis of the right lobe and jaundice Hofmeister s case of severance of the left hepatic showed extensive necrosis of the left lobe and of the spigelian lobe as well Further instances of severe necrosis when the left hepatic was cut were those of Wilms that showed extensive necrosis of the left lobe and ulceration of the vessel the case of Gaube and Herrenschmidt, that showed total necrosis of the left lobe and the case of Holst in which the left lobe became small and had areas of necrosis Graham and Cannell gave two illustrations of the necrotic areas found in their case at autopsy The necrosis did not involve the capsule of the liver or the liver substance immediately beneath it In their opinion the relatively small amount of liver necrosis observed was not sufficient to cause death nor were there any clinical signs or symptoms of liver insufficiency From this they inferred that if their patient had had an otherwise uncomplicated course he would have survived the damage done to the liver by ligation of the common hepatic Their concluding sentence reads

The rather delayed development of liver insufficiency in man contrasts sharply with the findings in experimental animals and makes successful operative interference a possibility (*Brit J Surg* 20 566 1933)

Therapeutic Ligation of the Hepatic Artery in Portal Hypertension

Fourteen years after Graham and Cannell of the University of Toronto Canada (1933) had suggested the possibility of an operative interference with the blood supply of the liver by ligating the hepatic artery without fatal issue Rienhoff of Johns Hopkins University (June 7 1947) successfully performed his first operation of ligating the hepatic and the splenic arteries in a bartender afflicted with a severe case of periportal alcoholic or Laennec s cirrhosis and portal hypertension The hepatic was ligated distal to the departure of the gastroduodenal the splenic at the site of its origin from the celiac After three and one half years (at time of publication 1951) the patient was still living Rienhoff stated that the rationale of his operation was based on the fact that

occlusion of the hepatic and the splenic is significant and may *account* for esophageal hemorrhage and that portal pressure may be *markedly reduced* by ligation of the splenic and the hepatic arteries

In an evaluation of the surgical results with the experimental ligature of the hepatic artery *in dogs* and applications thereof to man it is extremely important to know that the *biologic condition of the dog's liver is far different from that of the human liver* Most recently Brunschwig of the Memorial Center for Cancer and Allied Diseases New York (1953) maintains that while the liver of the dog is heavily infected with pathogenic anaerobes the human liver has proved to be sterile (Romieu and *Brunschwig* 1951) As a sequence to this Brunschwig (1953) concluded that any infectious process that may evolve after operation must be ascribed to exogenous sources

Ligation of the Hepatic Artery in Man

Previous to current surgical procedures clinical experiences with the purposeful ligation of the hepatic artery have been relatively few this fact being due to the disastrous results observed in animal experimentation Hans Kehr of Halberstadt Germany (1903) Europe's outstanding specialist on gall bladder surgery who visited the Mayo brothers in 1903 is the first to have successfully ligated the arteria hepatica propria distal to the point of origin of the gastroduodenal in a patient with aneurysm of the right hepatic artery A comparable ligation with successful cure was made by Sudeck (1919) and by Colmers (1921) for intrahepatic aneurysm Most recently Grant Fitts and Ravdin (1950) ligated the hepatic artery in two patients in whom hepatic aneurysm was diagnosed at operation but both died one from massive hepatic necrosis (despite treatment with streptomycin and penicillin) the other from recurrent hemorrhage In 1920 Behrend tried to save the life of a 12 year old boy who had been run over by a wagon with a resultant severance of the hepatic artery *He tied both ends of the severed hepatic* but the boy died Concerned as to whether ligation of the hepatic artery was responsible for the death Behrend thereupon investigated ligations of hepatic arteries in animals having at his disposal the advice and the opinion of Dr J Parsons Schaeffer then Director of the Daniel Baugh Institute of Anatomy of Jefferson Medical College

Surgical experiences with an accidental severance or ligation of the hepatic artery or one of its branches on the other hand have been many although in proportion to the mistakes that inadvertently have been made for obvious reasons relatively few have been reported in the literature Graham and Cannell of the University of Toronto Canada (1933) reported a case of a 49 year old man in whom the hepatic artery was accidentally ligated during a partial gastrectomy this fact having been ascertained following closure of the duodenal stump Although the patient became ill on the fourth day and died on the seventh day they were of the opinion that death was not due to liver insufficiency for only a relatively small amount of liver necrosis was observed at autopsy and a collateral circulation had apparently been established through the phrenic arteries and their diaphragmatic anastomoses

From a review of the 27 cases reported in the literature in which the hepatic artery or one of its branches had purposefully or accidentally been ligated and on the basis of their own case Graham and Cannell (1933) concluded that ligation of the hepatic artery is always a serious but not necessarily a fatal accident An analysis of their re

aimed at in the treatment of cirrhosis for here conditions of circulation are more or less the reverse of the normal In general the normal arterial circulation is represented by a high pressure small volume system whereas the portal circulation is represented by a low pressure large volume system The head of pressure in the hepatic artery which carries about 25 per cent of the total volume of blood reaching the liver (Burton Opitz 1911) normally varies between 120 and 130 mm Hg while the pressure in the portal vein which carries 75 per cent of the blood volume varies between 8 and 12 mm Hg Chenoweth refers to the studies on blood flow by Herrick (1907) in which it was noted that both the hepatic artery and the portal vein flowed into the sinusoids and that there was a direct arteriovenous connection between the branches of the artery and the vein proximal to the sinusoids In the production of portal hypertension according to Chenoweth the general thought seems to be that at least two factors are operating—viz the decrease in the available portal bed and an increase in the arterial bed the latter phenomenon probably being associated with abnormally large arteriovenous communications in the liver

Chenoweth stated that in both patients operated upon a vigorous machinerylike thrill was palpable along the course of the hepatic artery and that in the woman (in whom the splenic artery was also ligated) this thrill manifested itself as an audible bruit in the epigastrium The significance of the thrill was thought to be correlated with abnormal arteriovenous communications outside the liver Because of the presence of the thrill the hepatic artery was ligated close to the celiac artery The moment the ligature was applied the thrill ceased and disappeared

Chenoweth concluded his paper by stating that clinical experiences with the new therapeutic measure of ligating the hepatic artery in acute cirrhosis are at present too limited to draw definite conclusions as to its merits and that more additional information both experimental and clinical is needed to clarify the complex physiologic process involved in the alteration of the hepatic arterial circulation

Considerable additional information on the new measure of treatment for portal cirrhosis has been obtained as seen from the following reports and comments

In discussing the paper presented by Dr Rienhoff before the surgical group in Chicago on June 11 1952 Dr Philip Thorek stated that in the small series in which he had done hepatic artery ligation the results although not conclusive were nevertheless encouraging

> Although the clinical results in esophageal varices have been encouraging I have been unable to demonstrate roentgenologically a reduction in the size of these varices [1]

Rosenbaum and Egbert of Indianapolis (1952) were among the first to question seriously the Rienhoff operation After performing a ligation of the hepatic artery in a 40 year old man who had typical portal cirrhosis the patient died on the second postoperative day At necropsy the liver showed extensive necrosis and ischemic hemorrhagic infarcts of the cirrhotic lobule On the basis of these destructive results these authors concluded that the ligation may be a hazardous treatment for many individuals

Berman and Hull (1952) in 12 cases with advanced portal cirrhosis in which the hepatic the splenic and the left gastric were ligated obtained an immediate mortality of 25 per cent the over all mortality being 41 5 per cent They found evidence for the formation of col

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[1] *Arch Surg* 66 32 1953

lowering the intra-arterial pressure also lowers that of the portal vein The first operation being successful, Rienhoff performed five others all successfully, for in his report in 1951 he stated that

> the clinical manifestations of portal hypertension such as bleeding esophageal varices and/or ascites have been allayed by this surgical procedure (*Bull Johns Hopkins Hosp* 88 368 1951)

Rienhoff made a note of the fact that Philip Thorek of Chicago (son of Max Thorek) had comparable success in four cases but was careful to conclude his preliminary report with the following statement

> *It is not to be presumed that this operation will be successful in all patients in whom it may be used its success will depend to a large extent on the critical condition of the patient or the advanced age of the disease* (*Bull Johns Hopkins Hosp* 88 368 1951)

As a substitute for postcaval anastomosis omentopexy and splenectomy (the surgical procedures most commonly used in the treatment of portal hypertension), Everson and Cole (1948) advocated the ligation of the splenic artery in patients with portal hypertension who are poor risks They are of the opinion that, when the splenic artery is tied and the spleen is undisturbed there is a better opportunity for escape of the portal blood than with the spleen removed In the three patients in whom they performed the operation there was no evidence of necrosis of the spleen although there was a sharp reduction in its size due to atrophy Blain and Blain (1950) made splenic ligation the operation of choice in selected cases of portal hypertension and in Banti s syndrome A W Blain having used the operative procedure for the latter disease as early as 1918 *Ligation of the splenic* artery leaving the splenic vein open to remove waste products was practiced in thrombopenic purpura many years ago by Lemaire and Debaisieux of Louvain University [see van Goidsenhoven (1927)] and by v Stubenrauch (1929)

The new Rienhoff therapeutic treatment of ligating the hepatic artery in portal cirrhosis of the liver was performed successfully by Chenoweth (1952) in two patients, by Berman Muller Fisch and Martz (1952) in one patient and by Philip Thorek in four patients as of 1952 *Rienhoff s latest* report as to subsequent successful results was given in a paper he presented before the 101st Session of the American Medical Association in Chicago June 11 1952 the report later being incorporated in an article jointly written with Woods (1953) It was at this same session that the author presented some of his observations on the variational anatomy of *the hepatic arteries depicted in this atlas*

Chenoweth of Birmingham Alabama (1952) in his extensive report on two cases maintains that the new treatment (i e alteration of the hepatic arterial circulation by tying off the hepatic) is a decidedly new approach to the problem of producing a sustained fall in portal pressure Heretofore according to Chenoweth a variety of methods of choice have been employed to overcome ascites and esophageal varices characteristic manifestations of cirrhosis to wit omentopexy splenectomy injection of sclerosing substances into esophageal varices total gastric resection resection of esophagogastric junction excision of periesophageal veins and portacaval shunts

In justification of the Rienhoff operation Chenoweth refers to the experimental work of *Berman Koenig and Muller (1951) in dogs in which* it was shown that ligation of the hepatic artery at the celiac axis causes a fall of portal pressure of 10 to 20 mm of water and *that ligation of the splenic* artery after ligation of the hepatic causes an additional fall of 40 to 50 mm of water This fall of portal pressure is the goal

patients who were operated on primarily for bleeding esophageal varices 5 are dead and 5 alive a mortality rate of 50 per cent

In view of their experiences Rienhoff and Woods concluded that even in the poor risk patients it is still unproved whether ligation of the arterial blood supply to the liver will be efficacious in controlling bleeding from esophageal varices their results with ligation of the hepatic arteries being less successful than those they had with postcaval shunts In patients suffering with hemorrhage due to esophageal varices 80 per cent will be dead within a year or one and one half years if not operated on As regards this condition the authors stated that At this time we feel that one should be cautious about drawing any conclusion until further clinical studies and experimental observations have been made

Ligation of the hepatic and the splenic arteries in patients with ascites alone however is of definite benefit as proved by the fact that over a period varying from several months to 6 years after surgery Rienhoff and Woods noted that all were improved They state

> It would seem that the ligation of the hepatic and splenic arteries is of definite benefit in patients with ascites alone and we feel that this procedure should be continued so that its value may be firmly established (*J A M A* 152 687 1953)

The authors maintain that a double ligation of the arteries is sufficient a division of the vessels not being necessary to accomplish the beneficial results

From the reports reviewed it is obvious that nearly all investigators who ligated the hepatic artery in animals obtained necrosis of the liver as a result of the operation It is equally evident that most surgeons who have had experience with hepatic ligation for portal hypertension do not favor this therapeutic treatment to reduce portal pressure Witter and First (1953) cite Patek to the effect that one third of all patients with portal cirrhosis under medical treatment will have hematemesis and that of these only 50 per cent will be alive after the first year They furthermore state that of those that bleed from esophageal varices 20 per cent will die with their first hemorrhage For results of animal experimentation regarding the influence of the portal circulation on the restoration of the liver the reader is referred to the excellent review compiled by Gray and published in *Annals of the Royal College of Surgeons* England 8 351 1951

Complete Removal of the Celiac Axis for Gastric Carcinoma

In a paper presented before the American Cancer Society Denver Colorado (July 1952) Appleby of Vancouver British Columbia Canada outlined his startling new measure of removal of the celiac axis with exenteration of the stomach and its bed for gastric carcinoma Firmly convinced that surgery of any cancer must be radical enough to leave no residue and in accordance with other currently practiced multiple organ resections for carcinoma in June 1949 Appleby removed the celiac axis with *all its branches* exenterating en bloc the stomach the omentum the spleen and the distal two thirds of the pancreas with all attendant venous channels nerve plexuses and lymph nodes Before dividing the celiac the hepatic was cut proximal to the junction point of the gastroduodenal the functional integrity of the superior mesenteric having previously been inspected and confirmed Of the 13 *patients subjected* to this operation the first was alive after 12 months and 9 were alive 29 to 7 months after the operation at time of publication (1953) Diverse liver function tests revealed *no impair*

lateral circulation between the hepatic artery and the portal vein and between the hepatic artery and the hepatic vein in the liver substance

Jahnke Seeley and Palmer (1953) in their report of a case of a 28 year old soldier (with cirrhosis esophageal varices and massive hematesis) in whom the hepatic and the splenic were ligated maintain that previous to operation it is important to know the extent of collateral circulation for failure to interrupt large accessory channels could nullify the final result of surgery From their postoperative studies these authors concluded that ligation and division of the hepatic and the splenic at the celiac axis indicate the surgical procedure to be a failure on the basis of massive esophageal varices with measured pressure almost equal to that present prior to operation

Taylor and Rosenbaum (1953) on the basis of perfusion experiments on 4 normal and 11 cirrhotic human livers (in which it was noted that the blood flow is directly proportional to the hepatic arterial supply portal pressure having little influence on the flow) concluded that termination of the arterial blood flow in a badly crippled liver like the cirrhotic is an ill advised procedure They presented the following objections to ligation of the hepatic (1) the operation requires too much time (2 to 3 hours) and is very difficult to perform successfully (2) every bit of arterial blood supply should be preserved for the only hope of improving the blood supply to a cirrhotic liver is to supply more not less arterial blood (3) at operation the extent of collateral circulation cannot be determined (4) at operation there is no way to estimate the physiologic state of the liver in order to determine which patient may survive a ligation of the hepatic and which will die as a result of the operation (5) the operation should be abandoned until it definitely can be determined which patient it will help and in which patient it is contraindicated

Desforges and Campbell (1953) maintain that while the ability of the cirrhotic liver to withstand occlusion of its major arterial blood flow has been demonstrated ligation of the hepatic artery does little to ameliorate the disease for which it is practiced viz, portal hypertension

Sven Ramstrom of Sweden (1953) is utterly opposed to an interference with the blood supply of the liver After a dissection of 44 human bodies and experiments with rabbits over a period of four years he is firmly convinced that hepatic lesions of all kinds (toxic infectious and post traumatic) influence renal function impairing it and causing renal insufficiency even though the kidneys are normal This interplay is known as the hepatorenal syndrome In support of his contention he presents a case of traumatization of the abdomen in which a branch of the arteria hepatica propria was torn off The patient died in a state of renal failure and autopsy showed necrosis of the liver

The article by Rienhoff and Woods of the Johns Hopkins University School of Medicine (1953) contains further reports regarding the clinical experiences they had in the treatment of cirrhosis of the liver by ligation of various branches of the arterial blood supply to the liver and the spleen Since 1947 23 patients (in addition to the original 6 reported in April 1951) have been operated on All of these were regarded as being in a poor risk category The over all mortality of this series amounted to 30 4 per cent 6 having died in the immediate postoperative period in the hospital Of the 13 patients who presented themselves for operation primarily because of ascites 2 are dead and 11 improved the mortality rate being 16 3 per cent Of the 10

gastric trunk (the hepatic and the left gastric form a common trunk the lienal arises separately from the aorta or the superior mesenteric) (4) hepatogastric trunk (the hepatic arises separately from the aorta or superior mesenteric) (5) celiacomesenteric trunk (the superior mesenteric arises in conjunction with the celiac) (6) celiacocolic trunk (the middle colic or an accessory middle colic arises from the celiac) (Figs 28 56 17 21 10)

Obviously before removal of the celiac axis is attempted the exact site of origin of the middle colic must be inspected and confirmed lest with the removal of a celiacocolic trunk the transverse colon be deprived of its blood supply

Ten Collateral Routes Through Hepatic Arteries Arising from Sources Other than the Celiac —Common Hepatic Trunk

1 Through a replaced left hepatic from the left gastric (10 per cent Fig 11)

2 Through a replaced right hepatic from the superior mesenteric (11 per cent Fig 36)

3 Through a replaced right hepatic and a replaced left hepatic when both of these types are present there being but one celiac hepatic viz the middle hepatic derived from the gastroduodenal that in such instances comes off directly from the celiac artery the other branches being the left gastric and the lienal (1 per cent) (Fig 55)

4 Through a replaced common hepatic trunk that arises from the superior mesenteric (5 cases Fig 53) aorta (3 cases) (Plate II No 21) or left gastric (1 case in 500 dissections) the celiac hepatic being absent (Fig 20)

5 Through an accessory left hepatic from the left gastric (8 per cent Fig 11)

6 Through an accessory right hepatic from the superior mesenteric (7 per cent Fig 15)

7 Through an accessory right hepatic and an accessory left hepatic when the liver has five hepatic arteries three typical hepatic branches (right left and middle) from the celiac hepatic an accessory hepatic from the superior mesenteric and an accessory hepatic from the left gastric (1 per cent Fig 16)

8 Through a replaced right hepatic from the superior mesenteric and an accessory left hepatic from the left gastric or the reverse of this through an accessory right hepatic from the superior mesenteric and a replaced left hepatic from the left gastric when such a combination pattern is present (2 per cent) (Figs 17 18)

9 Through an accessory right hepatic stemming from the retroduodenal the gastroduodenal or the dorsal pancreatic artery the latter with a possible origin from the hepatic the splenic the superior mesenteric the aorta or the celiac (Fig 91)

10 Through a cystic artery either its superficial or deep branch which arises from the gastroduodenal or the retroduodenal artery the cystic upon reaching the gallbladder region giving off a variable number of branches to the liver substance *(4 per cent) (Figs 47 40)*

Six Collateral Pathways Outside the Hepatic Arteries but Capable of Connecting with the Severed Hepatic or Any of Its Three Main Branches (Right Left Middle Hepatic) via Branches Stemming Therefrom (Fig 100)

1 By the infragastric route (arcus arteriosus ventriculi inferior of Hyrtl) This epiploic (omental) pathway is situated in the anterior two layers of the great omentum 2 to 4 cm below the stomach and is made by the right and the left gastro epiploics as they anasto

ment nor was there any sign of liver necrosis For further details see his paper which appeared in *Cancer*, 6 704 1953

Possible Collateral Arterial Pathways to the Liver

Material Methods and the Celiac Axis

The statistical data for this chapter are based on dissections of the same 200 bodies *that constituted the material for* the entire atlas Of the 200 bodies examined over a period of 6 years in the dissecting rooms of the Daniel Baugh Institute of Anatomy of Jefferson Medical College 181 were male (117 white 64 colored) and 19 were female (13 white 6 colored) Their ages varied from 25 to 95 years the majority being more than 50 years of age In each instance the author personally dissected the arteries supplying the supramesocolonic organs and made sketches of them prior to their manipulation by *students The final details of terminal* ramifications and endings of the regional arteries were worked out in excised specimens these comprising in each instance all of the supramesocolonic organs en bloc

Celiac Axis

Ligation of the common hepatic trunk even at or close to the celiac axis does not necessarily mean that thereby the liver becomes deprived of its arterial blood supply for *in only 55 per cent of the population is the arterial blood supply of the liver a typical one,* as described in textbooks i e effected solely by a celiac–common hepatic trunk that divides into a right and a left hepatic branch (Fig 60) The widespread difference in hepatic vascularization is due to the constitutional difference of the celiac axis which resolves itself largely in the presence of aberrant hepatic arteries These as previously shown comprise two types (1) replaced hepatic arteries *i e those arising from a source* other than the celiac axis e g from the superior mesenteric or the left gastric and (2) accessory hepatic arteries i e additive arteries that come from sources other than the celiac A statistical estimate of the 200 dissections shows that an aberrant hepatic artery occurred in approximately every other body (41 5 per cent) and that 31 5 per cent of the bodies had but one aberrant hepatic while 10 per cent had two or more

Typically the short thick celiac trunk varies from 8 to 10 mm in length Its site of origin from the aorta is very close to that of the superior mesenteric (1 to 22 mm) the two arteries in some *instances arising contiguously In addi*tion to its three typical branches (left gastric hepatic and splenic [lienal] arteries) the celiac frequently gives rise to the dorsal pancreatic the right or the left inferior phrenic or both and sometimes to the middle colic or an accessory middle colic (Figs 74 40 41)

Complete removal of the celiac axis for gastric carcinoma as advocated by Appleby may involve the removal of more than one celiac vessel for quite frequently one or more of the celiac branches have an independent origin from the aorta or other source thereby giving rise to varied types of celiac axis

A statistical analysis of the 200 bodies investigated showed that a hepatolienogastric celiac trunk consisting of three branches—left gastric splenic (lienal) and hepatic (complete Fig 61 or incomplete Fig 59)—occurred in approximately 90 per cent The other types comprising the remaining 10 per cent were constituted as follows (1) hepatolienal trunk (hepatic and splenic form a common trunk the left gastric arises separately) (2) hepatolienomesenteric trunk (the same trunk but with the superior mesenteric added) (3) hepato-

edge of the lesser omentum as first shown by Piquand (1910) The arc may persist in its entirety (1 per cent) (Fig 72) If the lower half is lost the upper becomes an accessory left gastric (3 per cent) (Fig 63) In one quarter of the population the lower half persists and becomes either an accessory or a replaced left hepatic (Figs 19 66) Cardio esophageal branches stemming from the arc or from the respective vessels derived from it communicate with the cardio esophageal branches from the left gastric and with short gastrics from the splenic and the left gastro epiploic Blood routed from the left gastric the left gastro epiploic or the splenic relayed through this arc may reach a severed hepatic branch on the left side

5 By the transpancreatic route (circulus transpancreaticus) The pancreas lies in three interlocking arterial circles formed by the hepatic the splenic and the superior mesenteric none of which is the sole blood supply to the organ Through the pancreas numerous routes of collateral circulation are available With respect to the liver blood may leave the splenic via the arteria pancreatica magna or the arteria caudae pancreatis (distal branches of the splenic) and enter the transverse pancreatic (a left branch of the dorsal pancreatic) and through the right branch of the dorsal pancreatic enter either the right gastro epiploic the superior pancreaticoduodenal or the gastroduodenal to reach the liver provided the gastroduodenal takes origin from a remaining severed hepatic artery i e the right the left or the middle hepatic (Fig 100)

6 The retro esophageal route (circulus gastrolienophrenicus) It is effected by the recurrent branch of the left inferior phrenic before the latter enters the diaphragm Posterior cardio esophageal branches of the inferior phrenic may tie up with the cardio esophageal branches of an accessory or replaced left hepatic arising from the left gastric They may also tie up with those branches given off by an accessory left gastric that is derived from the left hepatic or with the cardio esophageal branches of an accessory left gastric coursing along the posterior surface of the stomach and derived from the splenic—the ramus esophagogastricus posterior ascendens not mentioned in the literature—or with a gastric branch given off by a superior polar lienal branch of the splenic In the fossa for the ligamentum venosum twigs from the recurrent branch of the left inferior phrenic may anastomose with the subcapsular plexiform branches of the hepatic (Fig 100)

Gastroduodenal and Right Gastric Arteries For clear thinking accurate orientation and identification it is advantageous to the surgeon to know the most common variational points of origin of the gastroduodenal and the right gastric arteries for *the left gastric has a relatively uniform origin* A statistical analysis of the 200 dissections showed that the gastroduodenal arose from a normal celiac–common hepatic trunk in 75 per cent leaving 22 5 per cent for the replaced types of gastroduodenals coming from the left hepatic (11 per cent) the right hepatic (7 per cent) the middle hepatic (1 per cent) or the replaced hepatic trunk (3 5 per cent) and 2 5 per cent for the gastroduodenals coming from other sources (the celiac or the superior mesenteric directly) (Figs 28 84 95 83 38 55 67)

In about half of the population the gastroduodenal artery arises at a point midway between the origin of the common *hepatic from the celiac and its division* into a right hepatic and a left hepatic branch Atypical origins of the gastroduodenal are correlated with variations in the mode of branching of the

mose along the greater curvature of the stomach The anastomosis may be effected as main vessels or in the form of a network of arteries and capillaries for the left gastro epiploic often falls short of full anastomosis (10 per cent) The arc gives off short ascending branches to the anterior and the posterior surfaces of the stomach and short and long branches (omental epiploic) to the great omentum the largest of these being the right epiploic and the left epiploic that descend in the great omentum to form an arc on its posterior layer (large epiploic arc) To the right the infragastric arc ties up with the gastroduodenal to reach the hepatic to the left cardio esophageal branches from the left gastro epiploic and short gastrics communicate with similar branches from the left gastric the left hepatic or from an aberrant *left hepatic arising* from the left gastric or from an accessory left gastric given off by the left hepatic

2 By the supragastric route (arcus arteriosus ventriculi superior) This omental pathway is situated along the lesser curvature of the stomach and is made by the anastomosis of the right gastric and the left gastric the latter being invariably much larger than the former While many of the branches of the left gastric communicate with the short gastrics derived from the splenic terminals and the left gastro epiploic its cardio esophageal branches frequently communicate with similar branches given off by a celiac–left hepatic or by an aberrant left hepatic stemming from the left gastric or by an accessory left gastric arising from *the left hepatic Via* the right gastric blood may enter a severed hepatic branch to wit the left hepatic (40 5 per cent) the right hepatic (5 5 per cent) the middle hepatic (5 per cent) *or enter the gastroduodenal (8* per cent) the cited percentages being the sites of origin of the right gastric as observed in 200 dissections

3 By the infracolic retro omental route (arcus epiploicus magnus of Barkow 1793) This important route is situated in the posterior layer of the great omentum 2 to 4 cm below the transverse colon where in the loosely arranged and expandable connective tissue of the great omentum it affords an excellent collateral arterial route for the liver the stomach and the spleen Vessels *involved in this route* are the left gastro epiploic and its descending left epiploic branch the arc itself the ascending right epiploic stemming from the right gastro epiploic the gastroduo *denal or the hepatic When the hepatic* trunk is cut the arc may still route blood into the liver if the gastroduodenal takes origin from the left hepatic (11 per cent) the right hepatic (7 per cent) *the middle hepatic (1 per* cent) the replaced hepatic trunk (3 5 per cent) or directly from the celiac or the superior mesenteric (2 5 per cent) The right limb of Barkow s arc may join the *transverse pancreatic artery* running along the inferior surface of the pancreas and through the latter s right branch become joined with the gastroduodenal via which it may unite with a severed hepatic The arc receives *the* long descending anterior epiploic arteries which at the peripheral free edge of the great omentum turn upward to join the arc From the arc posterior epiploics ascend to *the transverse colon* affording this enteric segment a blood supply additive to that furnished by the middle colic but not sufficient to maintain viability of this section of the gut *when the middle colic* has been severed

4 By the para esophageal hepatogastric omental route (circulus hepatogastricus) Developmentally considered this is a primitive arched anastomosis between the left gastric and the left hepatic situated at the left peripheral

enter into the residual severed hepatic or the hepatic branch that gave off the gastroduodenal and thus reach the liver

2 Through the superior mesenteric via the transverse pancreatic when the latter vessel takes origin from it directly or indirectly through a dorsal pancreatic stemming from the superior mesenteric or from an accessory middle colic After coursing along the inferior surface of the pancreas the transverse pancreatic artery unites with the arteria caudae pancreatis a branch given off by the splenic terminals or the left gastro epiploic at the tail of the pancreas Via the transverse pancreatic blood may be routed to the infragastric circle via the left gastro epiploic to the para esophageal circle via the short gastrics or to the gastro duodenal via the right branch of the dorsal pancreatic coursing in the pancreas (Fig 100)

3 Through the inferior phrenics Having entered the diaphragm the right and the left inferior phrenics branch and accordingly may communicate with branches of the hepatic arterial system for the liver because of its embryologic development in the septum transversum always maintains its intimate connective tissue union with the diaphragm (bare area) It is for this reason that Segall upon injecting the hepatic arteries with an emulsion of barium sulfate found the phrenic arteries more or less completely filled with the emulsion in all of the 37 human livers examined The manner in which cardio esophageal branches of the left inferior phrenic may anastomose with subcapsular branches of hepatic branches in the fossa for the ligamentum venosum is shown in Figure 100 In surviving dogs in which the hepatic arterial supply was completely excised Jefferson Proffitt and Necheles found evidence of a collateral circulation to the liver through the right and the left inferior phrenics

Typically the inferior phrenic after its origin from the aorta or the celiac courses to the dome of the diaphragm where it divides into two branches A smaller posterior branch proceeds laterally and posteriorly above the costal and the lumbar origin of the diaphragm to anastomose with the intercostals The larger anterior branch courses anteriorly and superiorly to the edge of the central tendon where it anastomoses with its fellow from the opposite side and with the musculophrenic branch of the internal mammary and with the pericardiacophrenic arteries Variationally considered the left inferior phrenic may arise independently or jointly with the right inferior phrenic from the aorta the celiac the left gastric or the lieno gastric trunk It may be united with a major branch of the left gastric with an accessory left gastric given off by a replaced left hepatic that sprang from the left gastric or from an aberrant left hepatic arising from the left gastric There may be two left inferior phrenics one arising from the celiac the other from an anastomotic vessel connecting the left gastric with the left hepatic or the one arising from the aorta the other from the left gastric (Figs 79 71)

4 Through the superior phrenics These vessels are a variable number of small diaphragmatic branches of the internal mammary that arise directly from it or from its terminal divisions i e the superior epigastric and the musculo phrenic Posteriorly a few superior phrenics may arise from the aorta After injection of a red lead dye into the aorta of dogs Jefferson Proffitt and Necheles noted a direct communication between the extrahepatic liver arteries and the right superior phrenic but never with the left superior phrenic

5 *Through the falciform ligament and the ligamentum teres* After ligation or division of the common hepatic or the celiac the terminal branches of the left and the middle hepatics coursing

celiac artery which are too numerous and complicated to be given here In summary it may be stated that typically the common hepatic after giving off the gastroduodenal divides into a right a middle and a left hepatic, the middle hepatic (for quadrate lobe) being a branch of either the right or the left hepatic When the common hepatic divides into the gastroduodenal and the right hepatic the celiac–left hepatic falls out and is replaced by a left hepatic from the left gastric (Fig 57) Similarly when the common hepatic divides into the gastroduodenal and the left hepatic the celiac–right hepatic falls out and is replaced by a right hepatic from the superior mesenteric (Fig 84) Finally when the common hepatic divides into the gastroduodenal and the middle hepatic both right and left hepatics are replaced from other sources (Fig 55) The blood supply to the liver may be accomplished by two separate main trunks arising from the aorta to wit a left trunk that supplies the left gastric the left hepatic and the splenic and a right trunk that supplies the right hepatic the middle hepatic the gastroduodenal and the right gastric (Fig 66) Since the celiac axis is often split each ligation of an artery supposedly the celiac should be preceded by individual inspection as to its constitution

As regards the origin of the right gastric most commonly it arises from the common hepatic trunk shortly after the latter has given off the gastroduodenal and before it divides into the right and the left hepatic branches When *origin of the right gastric* is delayed it arises from the proximal part of the left hepatic when advanced it arises from the proximal part of the gastroduodenal or from the hepatic trunk before the latter is given off (Figs 60 54 62 66) Quite frequently three or four of the main branches of the hepatic (right and left hepatic gastroduodenal and right gastric) arise from the hepatic trunk at the same point or in close proximity to one another (Fig 69) In some instances the right gastric stems from the middle hepatic (Figs 55, 59)

In the 200 dissections statistically estimated the right gastric arose as a branch of the following arteries (1) common hepatic in 80 cases (40 per cent) including hepatic trunks derived from the superior mesenteric or the aorta (1 5 per cent) (2) left hepatic in 81 cases (40 5 per cent) including the replaced left hepatics from the aorta and the superior mesenteric (2 per cent) (3) right hepatic in 11 cases (5 5 per cent) including replaced right hepatics from the aorta *the superior mesenteric and the* left gastric (1 5 per cent) (4) middle hepatic in 10 cases (5 per cent) (5) gastroduodenal in 16 cases (8 per cent) It is interesting to note that while the constancy of origin of the left gastric from the celiac amounted to *90 per cent, the constancy of origin of the right gastric fell to 80 per cent,* the common hepatic and the left hepatic sharing the site of origin in about equal proportion

Ten Collateral Pathways of Arterial Blood Supply to the Liver Outside the Celiac Blood Supply (Fig 100)

1 Through the superior mesenteric via its inferior pancreaticoduodenal branch or branches that in some instances may come from the first jejunal branch (Fig 73) Leaving the inferior pancreaticoduodenal blood may be routed through the anterior and the posterior pancreaticoduodenal arcades located on the anterior and the posterior surfaces of the head of the pancreas and reach the gastroduodenal through its superior pancreaticoduodenal or retroduodenal branch If the hepatic has been ligated proximal to the origin of the gastroduodenal blood from the superior mesenteric via the cited routes may

with injections and are difficult to remove. A small amount of life sustaining arterial blood may reach the liver through them.

10. Via filamentous arterioles that course along the common bile duct, the cystic duct and the hepatic duct; in many instances these take origin from the *retroduodenal artery as it crosses the common bile duct anteriorly or stem from the supraduodenal artery of Wilkie as the latter descends to the first part of the duodenum* (Figs 50-52). Appleby of Vancouver, Canada, in a personal communication (1951) states that from years of experience (to be reported soon) he is convinced that necrotic and nonviable conditions of the common duct are due primarily to taking away its blood supply furnished via cited routes, viz. the retroduodenal and the supraduodenal arteries. (See Below page 164.)

This point of view of the blood supply to the common duct was forcefully brought to the attention of the author by the late Dr De Muth of Canada, not only in his impressive address before the International College of Surgeons at Philadelphia in 1944 but also in a personal discussion of this very important item after the author at the same session had presented some of the illustrations (now finally reproduced in color in this atlas) regarding the blood supply of the common duct. A comparable comment was made by several leading European surgeons (in particular Bortolotti of Trieste, Bailey of England) after the author had presented the same slides before the 6th International Assembly of the International College of Surgeons in Rome, Italy, May 1948. Similar comments were made by surgeons at presentation of findings before the 60th Session of the American Association of Anatomists at McGill University, Montreal, Canada, April 1947, and at the Centennial Meeting of the American Medical Association, Atlantic City, June 1947, where in an exhibit 100 dissected liver specimens were demonstrated. Most of the large drawings shown in this atlas depicting the blood supply of the right and the left lobes, the quadrate and the caudate lobes of the liver had at that time been completed and were affixed by notification to the pertaining demonstrated specimens.

Summary and Applications

A study of 200 dissections revealed the fact that there are at least 26 possible different routes of a collateral blood supply to the liver besides the typical textbook type of a celiac blood supply made by a single common hepatic trunk. Classified, these routes comprise: (1) 10 different collateral pathways via aberrant hepatic arteries; (2) 6 pathways via a circuitous course through the lesser omentum, the great omentum and the pancreas to severed perfect distal hepatic branches that remain after ligation of the celiac–common hepatic; (3) 10 pathways effected outside the celiac (axis)-hepatic blood supply.

Terminal Hepatic Branches. Amazing indeed and unrecorded in the literature is the number of terminal hepatic branches coursing beneath the capsule of the liver and entering the liver substance at various points, especially in the umbilical fossa, the portal fissure and the fossa for the ligamentum venosum. In a *tedious detailed dissection* of 50 specimens made by the author, the number of arteries entering the liver varied from 17 to 65; 70 per cent of the specimens had between 20 and 30 arteries, 10 per cent between 30 and 40, the others had more than the last cited figures. Excluding 3 to 4 larger branches from the left hepatic and 5 to 7 larger branches from the right hepatic given off by the respective vessels before they entered the liver substance, the remaining extrahepatic branches were twiglike and prevailingly ran a subcapsu

in the falciform ligament are still in communication with the liver through rami previously supplied by the left and the middle hepatics to the left lobe and the quadrate lobe *These falciform arteries may accordingly bring in a reverse blood flow from vessels in the anterior body wall, viz, from the superior epigastric or from a separate direct branch of the internal mammary that supplies the fat body located in the midline between the posterior layer of the rectus sheath and the peritoneum and extending into the base of the falciform ligament, frequently in the form of an epiploic appendage This separate branch of the internal mammary 1 to 2 mm wide is known as the ramulus ad appendicem ensiformem et lineam albam of Haller (1753)* Its constancy has been confirmed by Nordenson Petren and Wising in 50 dissections Most commonly it arises at the cranial border of the seventh costal cartilage 3 cm from the midline courses along the lateral border of the ensiform process and caudal to the latter proceeds downward to supply the fat body in the falciform ligament (Fig 100)

6 Through arteries coursing in the layers of peritoneum reflected over the liver (coronary ligament right and left triangular ligaments) Largely of phrenic origin and anastomosing with subcapsular plexuses some of these represent branches of the intercostals the superior epigastrics and the aorta

7 Through the intercostal arteries *Not commonly taught but anatomically true* is the fact that the liver is definitely attached to the posterior abdominal wall at its right side the peritoneal reflection over the inferior vena cava—the hepatoportacaval ligament—proving it Arteries coursing here may enter the liver substance and bring a life sustaining blood supply to the liver Since the intercostals are anastomosed with the terminal branches of the inferior phrenic a further blood supply can be rerouted via this pathway For the most recent and comprehensive data on the development and the relational anatomy of the embryonic diaphragm (not done for 40 years) see the classical work of Wells of the Institute of Anatomy of the University of Minnesota (1954) This work begun under Boyden was conducted for the most part in the Department of Embryology Carnegie Institution of Washington Baltimore Md with the sustained interest of Dr Corner its Director

8 Through arteries that deeply situated in the posterior abdominal wall or coursing retroperitoneally may reach the liver via anastomoses on the right side where the liver is directly attached to the posterior abdominal wall Terminal branches of the upper lumbars may anastomose with branches from the lower intercostals these in turn with the phrenic branches in the diaphragm via which they may reach the hepatic arterial system

The right inferior phrenic not uncommonly arises from the renal artery or from a superior polar renal artery (Fig 68) At the areas at which the liver is attached to the diaphragm terminal branches of the phrenics may communicate with the intrahepatic branches of the hepatic *That the deep pathways of portasystemic communications are normally patent and of greater significance than the anterior parietal was shown by Edwards (1951) Arteries and arterioles in the retroperitoneal areas about the liver merit further extensive study and investigation, the problem of cancer metastasis here being largely involved, for cancerous growths in this region are frightfully quick in killing*

9 Via fine arterioles (vasa vasorum) in the hepatic veins the portal veins and the inferior vena cava the latter receiving a supply from the inferior phrenic These arterioles can be demonstrated

the retroduodenal or the supraduodenal, occasionally (5) between the cystic and the common hepatic or the right hepatic (2 cases) (Fig 82) (6) between the branches of the superficial and the deep cystic artery frequently (Fig 52)

Since most of the anastomoses between hepatic arteries occur near the liver they are in the majority of cases operatively undeterminable and inaccessible Their functional role in occlusion or severance of a major hepatic vessel has never been determined When ligation of the common hepatic is made proximal to the gastroduodenal a collateral circulation routed through the gastroduodenal may reach the entire liver via these hepatic anastomoses thus accounting at least in some instances for the maintenance of a life sustaining blood supply to the organ The extrahepatic anastomoses between the hepatic arteries however (aside from those occurring under the capsule of the liver between twiglike branches) are comparatively few and because of this fact cannot be relied upon to re establish a compensatory circulation when one of the main hepatic arteries has been severed

Ligation of the splenic artery in conjunction with the ligation of the hepatic does not materially alter the anatomic framework for possible collateral pathways although it does induce an additional fall in the portal pressure Through the splenic terminals notably the left gastro epiploic blood may be routed to the right to reach the right gastro epiploic and the gastroduodenal or to the left to reach the short gastric and through these via their anastomoses with hepatic branches again reach the liver The afferent blood supply can come from the superior mesenteric reaching the remaining intact gastroduodenal via the inferior pancreaticoduodenal and the anterior and the posterior pancreaticoduodenal arcades respectively made by the superior pancreaticoduodenal and the retroduodenal arteries as evidenced by the survival of patients after removal of the celiac axis in a block dissection of the stomach and its bed for carcinoma (Appleby, 1953)

Applications

As a surgical precaution and as an anatomic admonition it should always be borne in mind that the cited 26 collateral pathways of the blood supply to the liver are only possible at most probable routes Because of existent variational anatomy relatively few can definitely be relied upon to establish an adequate compensatory circulation in the liver when the main common hepatic trunk or the celiac has been ligated or severed The fact that some individuals have survived the therapeutic ligation of the common hepatic artery is counterbalanced by cases in which the result was fatal Graham and Cannell report cases in which ligation of the right hepatic or of the left hepatic alone has resulted in liver necrosis and death Behrend Gordon Taylor Vaughn Gray Glauser and Sven Ramstrom *have definitely committed themselves to the opinion that some of the so called liver deaths following cholecystectomy are attributable to severance ligation or clamping of the right hepatic artery*

Sven Ramstrom of Sweden (1953) after 4 years study (anatomic and experimental) is *firmly* convinced that hepatic lesions of all kinds (toxic infectious and post traumatic) influence renal function impairing it and causing renal insufficiency even though the kidneys are normal (hepatorenal syndrome) He emphatically stated that

> certain obscure deaths after apparently uncomplicated biliary operations could well be due to unintentional ligation of an anomalous branch of the hepatic artery (*Acta Chir Scandinav* 175 1–69 1953)

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lar course The nature of these sub capsular branches (*those running under Glisson s capsule*) remains an unsolved anatomic and physiologic problem for, *when necrosis of the liver sets in after* severance of a right or a left hepatic ar tery why is the superficial surface of the *liver for a centimeter or more spared (i e* kept viable) as noted in particular by Graham and Cannell of Canada in 1933[?]

Via these subcapsular extrahepatic twigs branches of the right hepatic often anastomose with branches of the middle hepatic and the *left hepatic especially* in the umbilical fossa In the fossa for the ligamentum venosum some of the subcapsular twigs anastomose with the recurrent branch of the left inferior phrenic The normal functional signifi cance of these subcapsular twigs the role they play in a cirrhotic liver or in main taining the life of the liver when the arterial blood flow through the common hepatic has been interrupted has never been determined The presence of these numerous anastomosing subcapsular ar teries may account for the observation of Graham and Cannell that after ligation of the common hepatic the resultant necrosis did not involve Glisson s cap sule or the liver substance immediately beneath it

Anastomosis of Hepatic Arteries Of great interest and importance to the sur geon when dealing with the interruption *of the celiac vascularization of the liver* and especially in hepatic lobectomies or in resections of the organ for removal of tumors is the extent of intrahepatic and extrahepatic anastomoses of the he patic arteries More than 30 years ago Martens in a roentgenologic study of specimens injected with Collargol and bismuth came to the conclusion that in a certain percentage the branches of the hepatic artery are *end arteries* in the sense of Cohnheim Thus far no defi nite proof has been given that the major *right and left hepatics* are extensively anastomosed within the liver Vinyl ace tate casts of the arterial vessels and bile ducts made by Healey and Schroy (1952) at the Daniel Baugh Institute of Anatomy of Jefferson Medical College in 100 human livers show *no evidence* of an appreciable anastomosis between *the blood vessels and the bile ducts of* the right and the left lobes

Many of the extrahepatic anastomoses *of the hepatic arteries encountered in* this study of 200 dissections are compar able with those occurring between the *lienal branches of the splenic* In an investigation of 100 spleens the author (1942) showed that the splenic arterial *anastomosis was restricted to extrahilar* **transverse anastomoses** between the ter minal lienal branches of the splenic (Fig 50) Comparable short transverse anastomoses occur frequently between the **terminal** branches of the hepatic especially in the umbilical fossa where the left hepatic and the middle hepatic are thus united and in the portal fissure where the caudate branch of the right hepatic gives off twiglike branches that unite with branches from the middle and the left hepatics Surgically considered, these fine juxtahepatic anastomoses *are inaccessible,* for they lie immediately be neath Glisson s capsule thus preventing their detection at operation (*Figs* 51 85 93)

The extrahepatic anastomoses of *major hepatic arteries* observed in this investigation comprised the following types (1) between the right hepatic and the left or the middle hepatic or between two branches of the right he patic frequently (2) between the celiac–right hepatic and an aberrant right hepatic from the superior mesen teric directly but only in a few cases (3) between the left hepatic and the left gastric via a small *artery coursing* in the peripheral edge of the lesser omentum frequently (4) between the hepatic or the right hepatic and the gastroduodenal

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easy Chenoweth found it extremely difficult to get access to and to expose the common hepatic trunk through either an abdominal incision or a thoraco abdominal approach This being the case it is still more difficult to locate and ligate *unknown* aberrant hepatic arteries arising from the superior mesenteric or the left gastric the latter often being hidden at the peripheral edge of the lesser omentum the former cryptically ascending behind the pancreas and in many cases partaking in its blood supply by giving off the inferior pancreaticoduodenal Bertocchi of the Torino University Italy (1958) recently confirmed this point in anatomic radiographic studies Cavalcanti of the National Faculty of Medicine of Brazil (1951) gave further evidence of the role played by the superior mesenteric and the left gastric in the blood supply of the liver

Obviously the exposition of and the manipulative facilities with hepatic arteries at operation can never approach the favorable conditions that were available to the author in human dissections in which through a wide transverse abdominal incision the supramesocolonic organs especially the liver were fully exposed and readily accessible It requires but a cursory survey of the dissections of hepatic vessels made in a large series of subjects in *any anatomic dissecting room* to convince the anatomist and the surgeon that the blood supply of the liver taken as a whole is effected through three sources viz the celiac the superior mesenteric and the left gastric the latter artery in this study having furnished an aberrant left hepatic in 46 cases

The role which so called *accessory hepatics* play in the intrahepatic arterial arrangement for a long time a much mooted and enigmatic problem has now definitely been solved as far as the gross aspects of the arteries are concerned From an investigation made at the Daniel Baugh Institute of Anatomy by Healey and Schroy on 100 human livers in which through vinyl acetate injections and the corrosion method the course and the distribution of arteries inside the liver have been made clearly visible in casts there is unquestionable evidence that all aberrant hepatic arteries (accessory or replaced) have a *selective segmental distribution* — i e they supply areas of liver parenchyma not nourished through branches stemming from the celiac–common hepatic trunk *Since no major intrahepatic anastomoses exist between the hepatic arteries inside the liver, the conclusion is warranted that severance of an aberrant right hepatic or left hepatic may have decidedly deleterious postoperative effects to wit, necrosis of the liver and death as has been reported in the literature in a series of cases reviewed by Ritter and by Graham and Cannell*

In patients who have survived ligation of the common hepatic artery or removal of the celiac axis some sort of collateral circulation obviously became established The anatomic nature and the extent of this compensatory collateral circulation await solution They might partly be solved by regional arteriograms in the living but in a definite anatomic manner it can be solved only after the patient operated upon has died—i e at a postmortem examination Such a waiting period was experienced by Wendel in 1920 for the woman in whom he had performed the first resection of the right lobe of the liver had died 9 years after the operation Wendel stated that the greatest hazard in the lobectomy was the maintenance of an adequate hepatic blood supply which he then discussed on the basis of his observations in specimens investigated with a contrast material in roentgenographs Like Martens he concluded that the right and the left hepatics are largely end arteries (idem Glauser 1953)

vestigating many of the author's specimens became extremely interested in regard to the varied points of entry of terminal hepatic branches and the areas of liver tissue they might supply. With no objection on the part of the author—to the contrary, with his hearty approval—he under the guidance of Dr Ravdin and Dr Batson of the University of Pennsylvania undertook an extended investigation of this important problem in the laboratories of the Harrison Department of Surgical Research using freshly obtained livers. By roentgenographic examination of injected branches of the hepatic artery Glauser (1953) definitely and clearly showed that *there is no arterial anastomosis in the human liver*. As a logical corollary he concluded that

These *studies raise the question whether* some cases of the hepatorenal syndrome could not be due to accidental occlusion of a relatively large end artery (*Surgery* 33 333 1953)

Healey and Schroy (1953) after a painstaking study of the segmental intrahepatic distribution of the hepatic arteries in 70 plastic corrosion casts made at the Daniel Baugh Institute of Anatomy of Jefferson Medical College found *no evidence for arterial anastomoses between the parenchymatous branches of the segmental arteries or their branches* and accordingly concluded that

It is our opinion that in the normal liver ligation of a segment artery will result in complete deprivation of arterial blood *to the segment of hepatic parenchyme* which it supplies (*J Internat Coll Surg* 20 133 1953)

In Ritter's report of the 29 cases of ligation of the hepatic or one of its branches that he found recorded in the literature (largely the same cases as those reported by Graham and Cannell) ligation of the common hepatic was followed by death in 3 to 4 hours in 66 per cent of the cases, ligation of the hepatic proper artery was fatal after 7½ days in 81 per cent, ligation of the right hepatic was followed by death after 8 days in 50 per cent, and ligation of the left hepatic resulted in death in 100 per cent after 10 days

Since the arterial vascularization of the liver varies in every instance in its terminal branching and *since in only about one half of the population (55 per cent) does a typical textbook pattern of a celiac-common hepatic trunk with a right and a left hepatic branch obtain* as noted in this investigation, it is but logical to conclude that in any one case the blood supply to the liver is unpredictable. Uniform results as to the beneficial effects of a therapeutic ligation of the common hepatic *cannot be expected* since an effective deprivation of the celiac blood supply to the liver by ligature of the common hepatic trunk is anatomically possible only in about every *other case* (45 per cent). The only absolutely effective method of preventing blood from entering the liver through the terminal hepatic branches is to ligate them as close to the liver as possible, i e distal to the point of origin of any vessel uniting with the left hepatic, including the cardio esophageal branches from an aberrant left hepatic arising from the left gastric or from an inferior phrenic. Aberrant right hepatics derived from the superior mesenteric must be severed close to the liver for they may carry the gastroduodenal and thus reroute blood via this vessel

The surgical procedure of eliminating the arterial blood supply to the liver in any individual is a *very difficult* one for the ligature of a common hepatic trunk coming from the common celiac *does not* mean that that vessel carries the entire hepatic blood supply. Furthermore as pointed out by Chenoweth and by Taylor and Rosenbaum the technic of ligating the common hepatic is definitely not

easy. Chenoweth found it extremely difficult to get access to and to expose the common hepatic trunk through either an abdominal incision or a thoraco-abdominal approach. This being the case, it is still more difficult to locate and ligate *unknown* aberrant hepatic arteries arising from the superior mesenteric or the left gastric, the latter often being hidden at the peripheral edge of the lesser omentum, the former cryptically ascending behind the pancreas and in many cases partaking in its blood supply by giving off the inferior pancreaticoduodenal. Bertocchi of the Torino University, Italy (1953) recently confirmed this point in anatomic radiographic studies. Cavalcanti of the National Faculty of Medicine of Brazil (1954) gave further evidence of the role played by the superior mesenteric and the left gastric in the blood supply of the liver.

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That some blood can reach the liver apart from the hepatic arteries, whether they are normal or aberrant and apart from the portal vein readily can be demonstrated experimentally by injecting India ink methylene blue or a barium mixture into the aorta after the portal vein and the hepatic artery have been ligated at the portal fissure After making an injection of an emulsion of barium sulfate in gelatin into the hepatic artery of human livers Segall noted that in all of his 37 specimens the inferior phrenics were more or less filled with the emulsion indicating that a collateral pathway of the hepatic blood supply was feasible through the inferior phrenics Since material injected into the right hepatic reached and filled the *left hepatic* it was concluded that a definite anastomosis existed between the vessels of the right and the left lobes Via the subcapsular plexus anastomoses with the inferior phrenics were established (1) *in the coronary and the triangular* ligaments (2) in the areolar tissue between the diaphragm and the liver (3) in the bare areas of the liver

The collateral pathways to the liver statistically analyzed and anatomically outlined in this study of 200 bodies are largely theoretical and *should by no means of deductive reasoning give rise to the impression that ligation of a major liver artery can be performed with impunity* The actual efficiency of the cited collateral pathways many of them small and inconspicuous can only be determined in further studies such as animal experimentation arteriograms and post mortem investigations

In view of current surgical procedures in modifying the afferent vessels to the liver, both arterial and portal and especially in *furtherance of cancer studies, the problem of intrahepatic and extrahepatic circulation merits renewed extensive investigation* As stated by Gray many abnormal conditions of the liver may not be due to the direct or specific action of the pathogenic agent that may initiate the illness but to a secondary phenomenon consequent upon a derangement of the intrahepatic circulation If arterial blood alone is responsible for the nutrition of metastases through the hepatic artery as it seemingly is for portal blood takes no part in the nutrition of tumor metastases in the liver (Markowitz and Rappaport) it becomes of paramount importance to know the blood supply of the liver not only as accomplished through the hepatic arterial system but also as effectively producible through collateral pathways

This descriptive atlas on the blood supply of the upper abdominal organs may be concluded fittingly with the literary citation with which Pedro Belou of Buenos Aires, Argentina captioned his classical monograph on the biliary ducts and the cystic artery in 1915 to wit

Hatez vous lentement, et sans perdre courage
Vingt fois sur le metier remettez votre ouvrage
Polissez le sans cesse et le repolissez
Ajoutez quelque fois et souvent effacez

L Art Poetique —BOILEAU

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Blood Supply and Anatomy of the Upper Abdominal Organs

Descriptive Atlas

Plates I to VI

Figures 1 to 165

Plates I to VI

Schematic drawings of 100 of the 200 statistically analyzed dissections of the blood supply to the supracolonic organs made by the author at the Daniel Baugh Institute of Anatomy of Jefferson Medical College over a period of 6 years and upon which this atlas primarily is based With few exceptions the sketches are but miniature reproductions of the arterial relations illustrated in the large drawings Figures 1 to 152

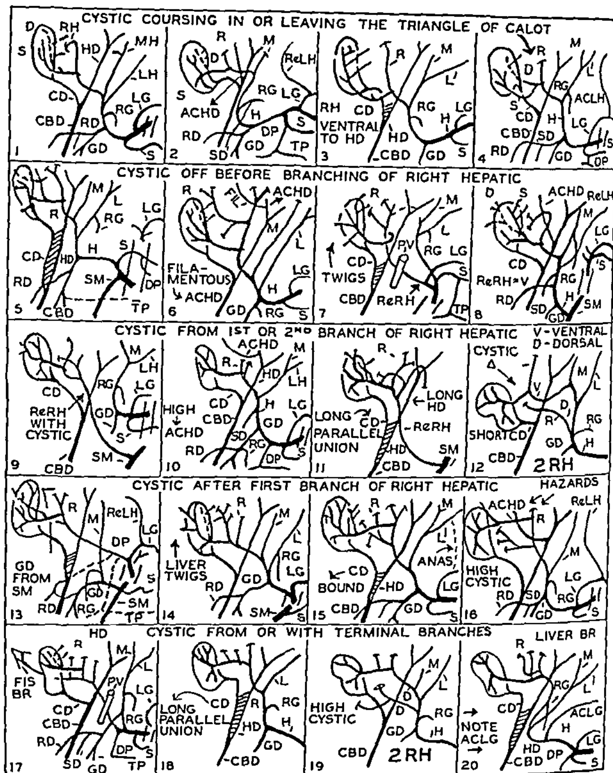


PLATE I Varied points of origin of the single cystic artery (C) in the cystic triangle of Calot of Budde and of Belou Boundaries of the cystic triangle are inferolaterally cystic duct (CD) medially hepatic duct (HD) cephalad right hepatic artery (RH) or cystic artery (C) If such a triangle does not exist the careful making of it as depicted in this anatomic atlas will help orientation of structures it being the advised operative procedure of many experienced surgeons with whom the author has discussed the problem both here and abroad

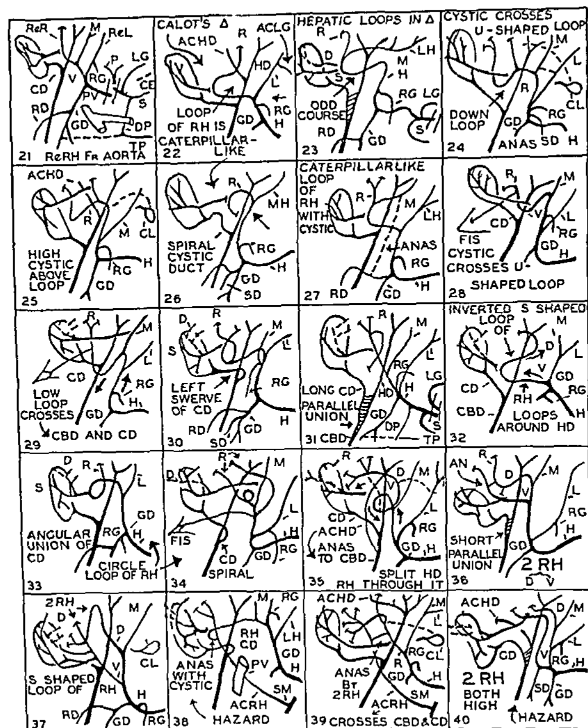


PLATE II Varied manner in which the right hepatic (RH) makes a characteristic at times phenomenal caterpillarlike loop inside and outside the cystic triangle Loops may be upward downward sidewise single or double and in some instances constitute a full circle twist inside or outside the triangle In the most bizarre loop formation encountered (No 35) *the RH seemingly* passed through a split hepatic duct (HD) it actually being a case in which an accessory hepatic duct (AcHD) anastomosed with the common bile duct (CBD) Unlike the splenic artery the hepatic artery is seldom tortuous and of excessive length

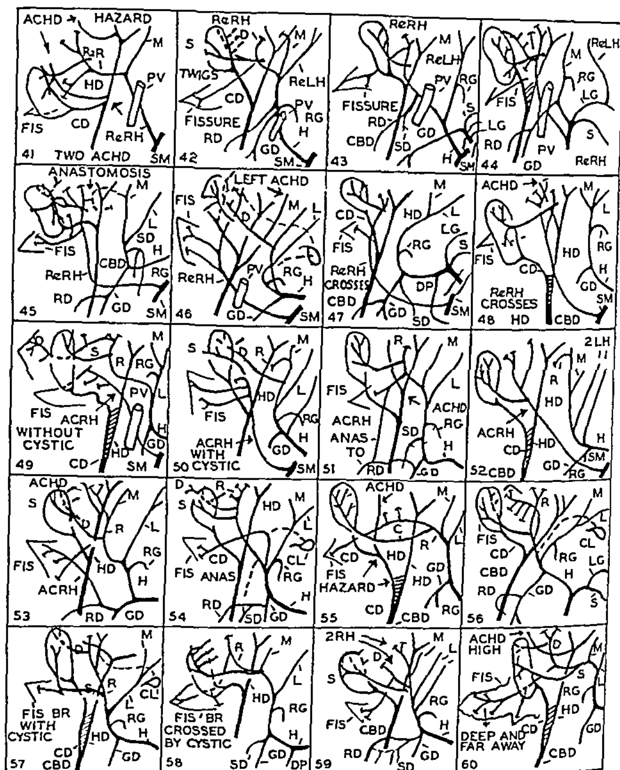


PLATE III Varied samples of the manner in which the right hepatic (RH) and the superior mesenteric (SM) give off a branch or branches to the fissured area (FIS) under the gallbladder (GB) the fissured area being but a normal lateral extension of the porta hepatis Surgically considered through a needless deep probing (2 to 5 mm deep) of omental tissue which as a rule safely covers fissured area branches one of them may be exposed and thus be mistaken for the cystic (C) having a resemblance to it An artery running parallel with the cystic duct (CD) and looking like the cystic artery need not necessarily be the cystic as emphasized from many years of surgical experience by Cole of the University of Illinois in a discussion of the author s paper presented before the surgic at the 101st A M A convention in Chicago in 1952

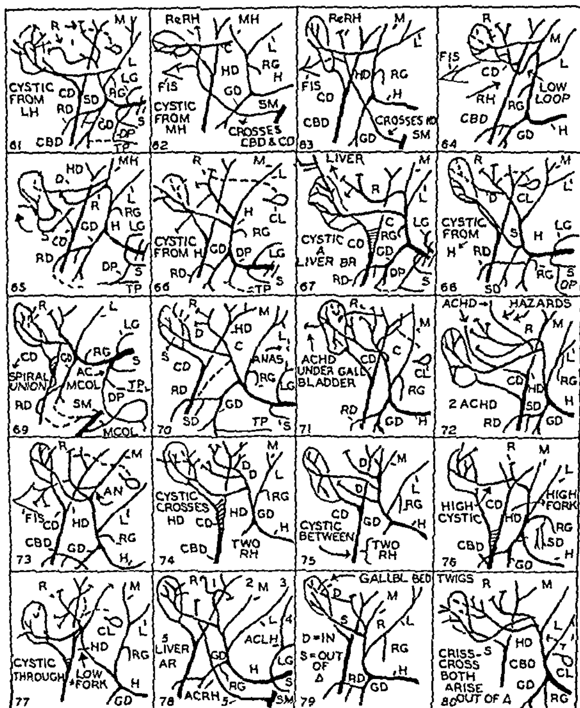


PLATE IV Varied samples of the mode of origin of the cystic artery (C) outside the cystic triangle of Calot which fact surprisingly occurred in approximately 20 per cent of the specimens In its extratriangular origin the C may stem from right hepatic (RH) middle hepatic (MH) left hepatic (LH) *hepatic* proper (H) gastroduodenal (GD) retroduodenal (RD) and even from superior mesenteric (SM) (*Belou*) Depicted likewise are samples of dual cystic arteries one or both of which arise outside the cystic triangle

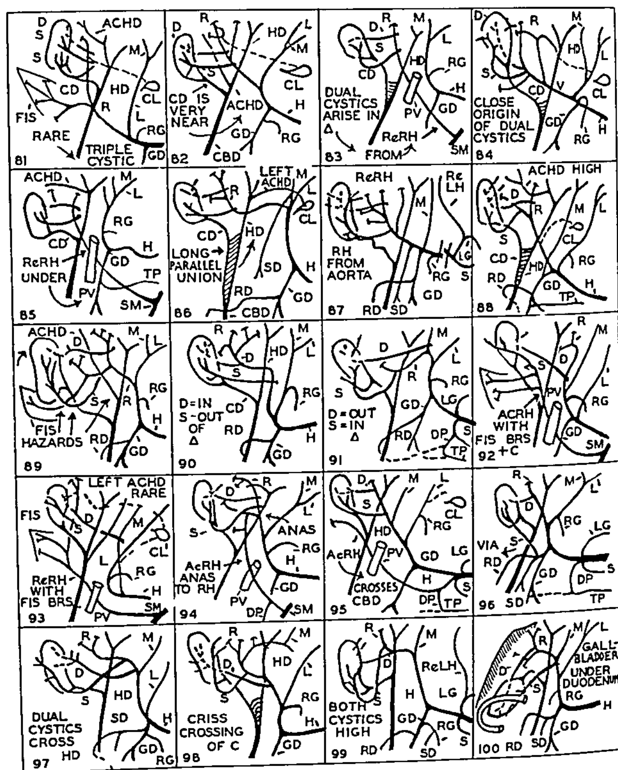


Plate V Varied samples of dual cystic arteries (C) (25 per cent of 200 speci mens) due to the fact that the superficial (SC) and the deep (DC) branches of the C may arise separately from the same artery inside the cystic triangle outside it one or both arising inside or outside the triangle André Wesal (latinized name is Vesalius of Brussels 1511–1564) referred to the SC and the DC as the gemellae cysticae

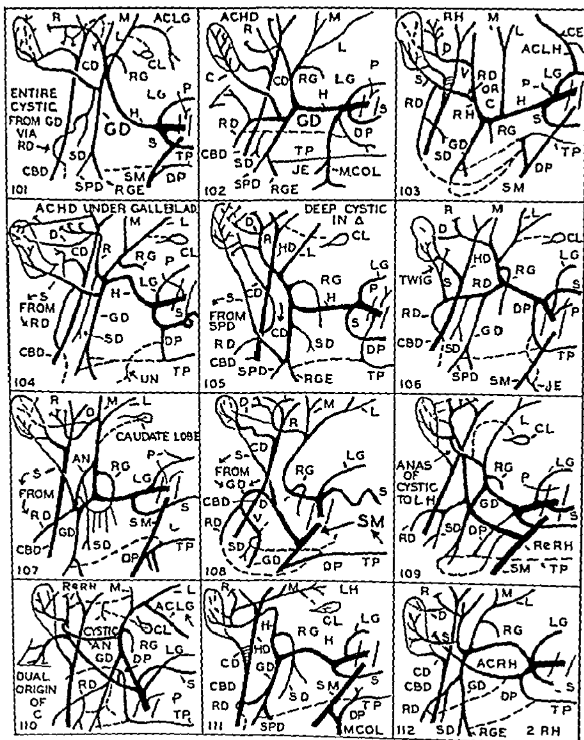
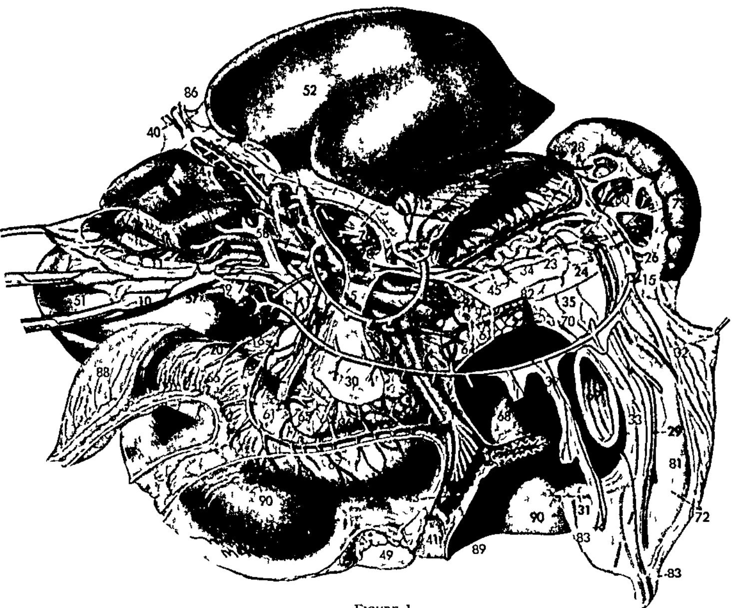


PLATE VI Varied samples of the entire cystic (C) arising outside the cystic triangle from the gastroduodenal (GD) or its retroduodenal branch (gut artery) (i e below the cystic duct CD) thus reversing the relations of the cystic triangle and samples of dual C one arising in the cystic triangle the other outside it or of both arising inside or outside the triangle



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FIGURE 1

Fig 1 Typical blood supply of the supramesocolonic organs In this illustration the various depths at which the structures and the recesses actually lie and in which the arteries course are shown in proper perspective for the first time The specimen was taken from an adult male and dissected by the author The drawing was made by W B McNett a pupil of Brodel s using the author s pencil sketch as a guide (In Figure 536 of Morris *Human Anatomy* ed 11 (by Schaeffer) 1953 published by McGraw Hill Blakiston Division the illustration is produced in black and white)

Explanatory Notes The celiac arterial pattern presented occurs in about one half of the population (55 per cent) in the other half decided variations exist The celiac hepatic divides into a right a left and a middle hepatic the latter (for the quadrate lobe QL) being given off by the left hepatic (LH) The single cystic artery (C) arises from the right hepatic (RH) in Calot s triangle and divides into its superficial (SC) and deep (DC) branches The RH divides into its anterior and posterior segmental branches for the respective segments of the right lobe The LH divides into its superior and inferior area branches of the lateral segment of the left lobe The middle hepatic (MH) courses under the portal vein (PV) to become distributed to the medial segment (quadrate lobe QL) of the left lobe These statements are in accord with the vinyl plastic casts of human livers made by Healey and Schroy at the Daniel Baugh Institute of Anatomy

The major part of the stomach has been removed to show the retrogastric space of the omental bursa bounded dorsally by the pancreas The supragastric circle made by the right and the left gastric arteries (RG and LG) and the infragastric circle made by the right and the left gastro epiploic arteries (RGE and LGE) are shown About the head of the pancreas are an anterior and a posterior retroduodenal arcade the former made by the superior pancreaticoduodenal artery (SPD) the latter by the retroduodenal artery (RD) Both arcades join the superior mesenteric artery (SM) via a common inferior pancreaticoduodenal artery (IPD) The supraduodenal artery of Wilkie (SD) to the first part of the duodenum has had a section of it removed The splenic (S) is characteristically tortuous and distally supplies a superior polar artery (SP) to the spleen before dividing into its superior and inferior terminal branches

Arising from the first part of the S near the junction point of the splenic vein (SV) with the superior mesenteric vein (SMV) is the dorsal pancreatic (DP) After supplying the neck region of the pancreas it gives off the transverse pancreatic (TP) which courses along the inferior surface of the pancreas at the tail end of which it anastomoses with the arteria pancreatica magna of the S and the arteria caudae pancreatis from the LGE To the right it is anastomosed with the SM

The anterior and the posterior walls of the inferior recess of the omental bursa in the great omentum are shown Situated in the posterior wall of the great omentum below the transverse colon is the large epiploic arc of Barkow the left limb of which is made by the left epiploic (LE) from the LGE The right limb is not shown but is made by a right epiploic (RE) from the RGE Descending branches (anterior epiploics AE) from the infragastric arterial circle end in the arc as do some of the descending branches (posterior epiploics PE) given off by the TP coursing in the pancreas The arc gives an additive blood supply to the transverse colon but it is not sufficient for survival of this enteric segment when the middle colic (MCol) has been cut

After its origin from the gastroduodenal artery (GD) the RD swerves around the common bile duct (CBD) supplying it and the ampulla of Vater in its course The retroduodenal arcade with its branches to the duodenum is faintly visible behind the head of the pancreas The caudate lobe (CL) is supplied by a branch of the MH

The cystic triangle of Calot is formed by the angular union of the cystic duct (CD) with the hepatic duct (HD) The latter receives 3 ducts which according to the plastic casts made by Healey and Schroy most probably represent a right duct from the anterior and the posterior segments of the right lobe a medial segmental duct from the medial segment and a lateral segmental duct from the lateral segment of the left lobe

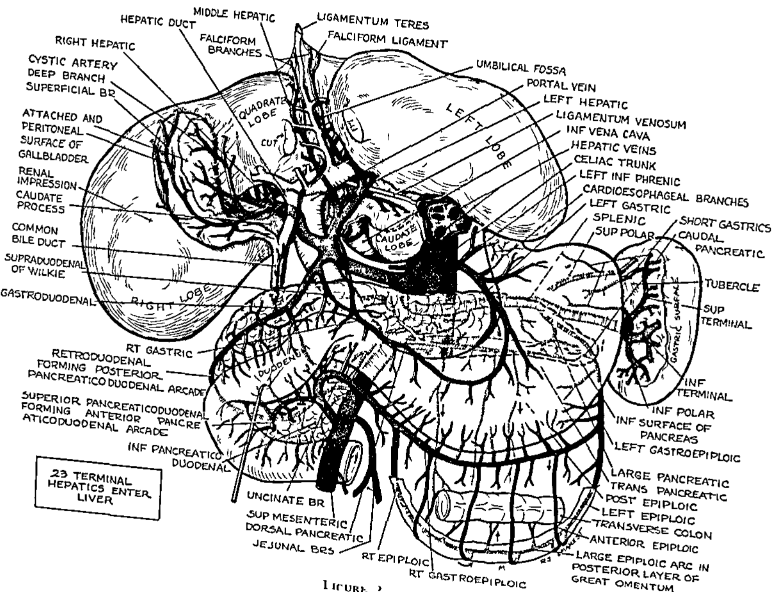
(Key to numbers on Figure 1 on pp 362 and 363)

Key to Numbers on Figure 1

Arteries and Veins

1 Celiac artery axis or trunk (CA) (CTr)
2 Common hepatic artery (H)
3 Splenic (lienal) artery (tortuous) (S) with early terminals
4 Left gastric artery (LG) with typical bifurcation
5 Right gastric artery (RG) always smaller than LG
6 Left hepatic artery (LH)
7 Right hepatic artery (RH)
8 Middle hepatic artery (MH) to quadrate lobe (QL)
9 Cystic artery (C) from RH in Calot's triangle
10 Superficial branch of cystic artery (SC)
11 Deep branch of cystic artery (DC)
12 Cardio esophageal branches (CE) of left gastric artery (LG)
13 Gastroduodenal artery (GD)
14 Right gastro epiploic artery (RGE) terminal branch of GD
15 Left gastro-epiploic artery (LGE) from splenic terminal
16 Superior pancreaticoduodenal artery (SPD) GD terminal
17 Retroduodenal artery (posterior superior pancreatico duodenal) (RD) a collateral branch of the GD
18 Common inferior pancreaticoduodenal artery (CIPD)
19 Superior mesenteric artery (SM) with intestinal rami
20 Supraduodenal artery of Wilkie (SD) to first inch of duodenum from GD, a section of it cut away
21 Dorsal pancreatic artery (DP)
22 Transverse pancreatic artery (inferior pancreatic) (TP)
23 A pancreatica magna (PM) of splenic artery (S)
24 Caudal pancreatic artery (CP) of left gastro-epiploic artery (LGE) anastomosing with TP
25 Superior polar artery (SP) of splenic artery (S)
26 Inferior polar artery (IP) of left gastro epiploic artery (LGE)
27 Superior and inferior splenic terminals (ST) (IT)
28 Short gastrics (SG) from splenic terminals
29 Left epiploic artery (LE) from left gastro epiploic artery (LGE), forms left limb of arc of Barkow
30 Right epiploic artery (RE) (cut) from right gastro-epiploic artery (RGE) forms right limb of arc
31 Arcus epiploicus magnus (of Barkow) in posterior layer of greater omentum
32 Anterior epiploic arteries (AL) in anterior layer of greater omentum
33 Posterior epiploic arteries (PL) in posterior layer of greater omentum with twigs to transverse colon
34 Pancreatic ramus of splenic artery (S) 3 7 present
35 Posterior epiploic arteries from transverse pancreatic artery (TP) to transverse mesocolon (TrCol) (2–5)
36 Pancreatic rami of inferior pancreaticoduodenal artery (IPD)
37 Ramus on common bile duct (CBD) which it supplies derived from retroduodenal artery (RD)
38 Anastomosis of right (RG) and left (LG) gastrics along lesser curvature with gastric branches
39 Anastomosis of right (RGE) and left (LGE) gastro epiploics along greater curvature with gastric and anterior epiploic branches Anastomosis absent in 10%
40 Ensiform branches of internal mammary uniting with falciform branches of left (LH) and middle (MH) hepatics
41 Aorta (A)
42 Portal vein (PV) with right and left branches
43 Superior mesenteric vein (SMV) with intestinal tributaries
44 Inferior mesenteric vein behind pancreas
45 Splenic vein (SV) with left gastro epiploic vein (latter cut)
46 Coronary vein (cut)
47 Cystic vein (deep branch)
48 Tributary vein from quadrate lobe (QL)
49 Inferior vena cava (IVC)
50 Left umbilical vein (remnant partly patent)

51 Renal impression of right lobe
52 Tuber omentale of lateral segment of left lobe
53 Quadrate lobe (QL) (medial segment of left lobe)
54 Caudate lobe (CL) with branch from middle hepatic artery (MH)
55 Pons hepatis (cut to show umbilical fossa)
56 Peritoneal and attached surface of gallbladder (GB) and gallbladder fossa with superficial and deep cystics
57 Cystic triangle (of Calot of Budde or of Belou)
58 *Hepatic duct (HD) with right left and middle hepatic duct*
59 Cystic duct (CD) angular union with HD
60 Common bile duct (CBD) with artery from retroduodenal (RD)
61 *Pancreatic duct cut its union with CBD shown*
62 Stomach (cut) Anterior branch of LG cut
63 Spleen with distributed type of vascularization
64 Neck of *pancreas (cut) showing location of dorsal pancreatic* artery (DP)
65 Head of pancreas (cut) showing confluence of pancreatic duct with CBD
66 Posterior surface of duodenum turned forward showing blood supply from retroduodenal (RD)
67 Infracolic (3rd) part of duodenum
68 Beginning of jejunum
69 Transverse colon in posterior layer of greater omentum
70 Transverse mesocolon (TrCol) with posterior epiploic arteries
71 Lesser omentum Gastrohepatic ligament (cut)
72 Anterior and posterior layers of greater omentum
73 Gastrosplenic (lienal) ligament (windowed)
74 Hepatoduodenal ligament (opened)
75 **Epiploic foramen (of Winslow) Entrance to omental bursa**
76 Vestibule of omental bursa (at arrow shadow)
77 Superior recess of omental bursa (arrow pointing to it)
78 Isthmus of omental bursa between gastropancreatic and hepatopancreatic folds former overlying left gastric and coronary vein latter common hepatic
79 Cavum retrogastricum or retrogastric space of omental bursa
80 Splenic recess of omental bursa (lateral extension of 79)
81 Inferior recess of omental bursa in greater omentum (caudal extension of 79)
82 Posterior secondary peritoneal wall of omental bursa
83 Anterior layer of greater omentum with anterior epiploic artery (AE) (strip of)
84 Umbilical fossa opened by dissection
85 Falciform ligament with branches of *MH* and *LH* arteries
86 Ligamentum teres hepatis (LT) (round ligament)
87 Appendix fibrosa hepatis Left triangular ligament
88 Pyloric end of stomach (cut and turned forward)
89 Root of mesentery of small intestine
90 Kidney with area crossed by transverse colon



MIDDLE HEPATIC
LIGAMENTUM TERES
HEPATIC DUCT
FALCIFORM BRANCHES
FALCIFORM LIGAMENT
RIGHT HEPATIC
CYSTIC ARTERY
DEEP BRANCH
SUPERFICIAL BR
UMBILICAL FOSSA
PORTAL VEIN
LEFT HEPATIC
LIGAMENTUM VENOSUM
INF VENA CAVA
HEPATIC VEINS
CELIAC TRUNK
LEFT INF PHRENIC
CARDIOESOPHAGEAL BRANCHES
LEFT GASTRIC
SPLENIC
SUP POLAR
SHORT GASTRICS
CAUDAL PANCREATIC
TUBERCLE
SUP TERMINAL
INF TERMINAL
INF POLAR
INF SURFACE OF PANCREAS
LEFT GASTROEPIPLOIC
LARGE PANCREATIC
TRANS PANCREATIC
POST EPIPLOIC
LEFT EPIPLOIC
TRANSVERSE COLON
ANTERIOR EPIPLOIC
LARGE EPIPLOIC ARC IN POSTERIOR LAYER OF GREAT OMENTUM
RT GASTROEPIPLOIC
RT EPIPLOIC
JEJUNAL BRS
DORSAL PANCREATIC
SUP MESENTERIC
UNCINATE BR
INF PANCREATICO DUODENAL
SUPERIOR PANCREATICODUODENAL FORMING ANTERIOR PANCRE ATICODUODENAL ARCADE
RETRODUODENAL FORMING POSTERIOR PANCREATICODUODENAL ARCADE
RT GASTRIC
GASTRODUODENAL
SUPRADUODENAL OF WILKIE
COMMON BILE DUCT
CAUDATE PROCESS
RENAL IMPRESSION
ATTACHED AND PERITONEAL SURFACE OF GALLBLADDER
QUADRATE LOBE
CUT
LEFT LOBE
RIGHT LOBE
CAUDATE LOBE
DUODENUM
GASTRIC SURFACE
23 TERMINAL HEPATICS ENTER LIVER

FIGURE 2

Fig 2 Typical and key labeled pattern of the blood supply of the upper abdominal organs Complete hepatolienogastric celiac trunk (CTr) with the left gastric (LG) as its first branch Single cystic (C) (M N 51 yrs)

The hepatic artery (H) after giving off the gastroduodenal (GD) divides into its 3 main branches—right middle and left hepatic—the middle hepatic (MH) for the quadrate lobe (QL) being a branch of the left hepatic (LH) The right hepatic (RH) crosses the hepatic duct (HD) posteriorly (81%) to reach the cystic triangle of Calot

The C from the RH divides into a superficial (SC) and a deep (DC) branch the gemellae cysticae of Vesalius The SC is distributed to the peritoneal free surface of the GB the DC to the nonperitoneal and attached surface and to the GB bed Both C give off liver twigs

The MH from the LH after supplying the caudate lobe (CL) proper courses in the umbilical fossa (which has been opened by cutting the pons hepatis) to supply the QL Both the MH and the LH give off falciform branches to the falciform ligament where they may anastomose with the ensiform branch of the internal mammary thereby establishing a collateral pathway to the liver from vessels above the diaphragm The caudate process is supplied by a branch of the RH 23 terminal hepatics enter the liver

The duodenum has been turned partly forward to show the posterior pancreaticoduodenal arcade made by the retroduodenal artery (RD) on the back of the head of the pancreas The primary branches from the arcade are distributed to all 3 parts of the posterior wall of the duodenum hence the term retroduodenal artery The arcade supplies the common bile duct (CBD) sends a few twigs to the pancreatic tissue and unites with the superior mesenteric (SM) via its own inferior pancreaticoduodenal (IPD)

The anterior pancreaticoduodenal arcade is made by the superior pancreaticoduodenal (SPD) It supplies the anterior wall of the duodenum with numerous branches gives off a more copious supply to the pancreatic tissue and unites with the SM via its own IPD In every instance therefore there are 2 pancreaticoduodenal arcades—one anterior one posterior Most frequently they join the SM via a common IPD

The dorsal pancreatic artery (DP) is a branch of the SM instead of the first part of the splenic (S) or the H Located near the junction point of the splenic vein (SV) with the superior mesenteric vein (SMV) it supplies the neck region of the pancreas in the back To the left it gives off the transverse pancreatic artery (TP) which courses along the inferior surface of the pancreas at the tail end of which it unites with the large pancreatic (a pancreatica magna PM) from the S and with the caudal pancreatic (a caudae pancreatis CP) from the left gastro-epiploic (LGE) Along its course the TP gives off several posterior epiploic (PE) (omental) branches to the transverse mesocolon (TrCol) To the right the DP gives off 2 branches One unites with the right gastro epiploic (RGE) the other supplies the uncinate process (Un) The supraduodenal artery of Wilkie (SD) is a branch of the GD It supplies the first inch of the duodenum anteriorly and posteriorly

The S is magistral in type i e it proceeds to near the hilus of the spleen before breaking up into its superior (ST) and inferior (IT) terminal branches As is frequently the case the spleen has a superior (SP) and an inferior (IP) polar artery these being comparable with and as varied as the polar arteries of the kidney The cardio esophageal end of the stomach has a copious blood supply receiving branches from the LG the left inferior phrenic (LIP) and the short gastrics (SG) from the S The LG is invariably larger than the right gastric (RG)

The RGE arises separately from the SM It gives off jejunal branches to the critically vascularized duodenojejunal junction supplies the SPD sends a communicating branch to the GD and is widely anastomosed with the smaller LGE A right epiploic (RE) from the RGE and a left epiploic (LE) from the LGE proceed down in the omentum where they form the right and the left limbs of the large epiploic arc (arcus epiploicus magnus of Barkow) in the posterior layer of the great omentum below the transverse colon The arc receives other descending anterior epiploic (AE) branches from the infragastric vascular arc and sends ascending branches to the transverse colon some of which unite with the PE descending from the TP coursing along the inferior surface of the pancreas Separate origin of the inferior phrenics (P) from the aorta (A)

Angular type of union of the CD with the HD Lengths of the ducts CD 2.5 cm HD 3 cm CBD 7.5 cm

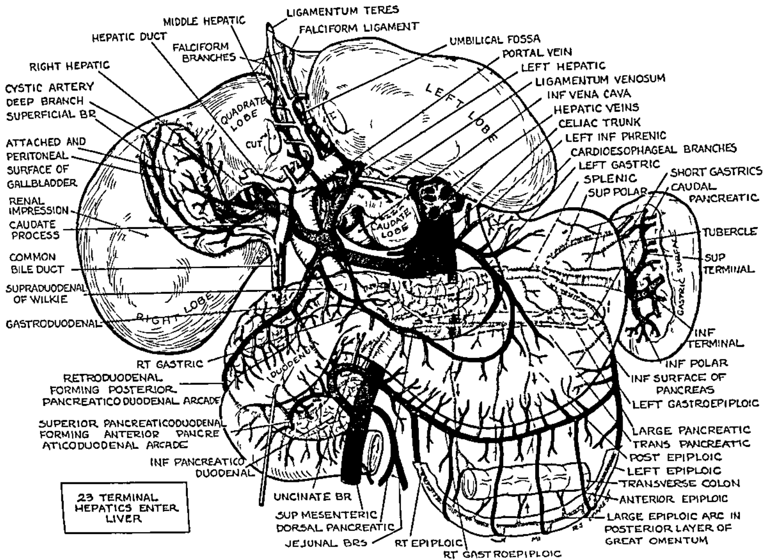

LIGAMENTUM TERES
MIDDLE HEPATIC
FALCIFORM LIGAMENT
HEPATIC DUCT
FALCIFORM BRANCHES
UMBILICAL FOSSA
PORTAL VEIN
RIGHT HEPATIC
LEFT HEPATIC
LIGAMENTUM VENOSUM
CYSTIC ARTERY
DEEP BRANCH
SUPERFICIAL BR
INF VENA CAVA
HEPATIC VEINS
CELIAC TRUNK
QUADRATE LOBE
LEFT LOBE
CUT
ATTACHED AND PERITONEAL SURFACE OF GALLBLADDER
LEFT INF PHRENIC
CARDIOESOPHAGEAL BRANCHES
LEFT GASTRIC
SPLENIC
SHORT GASTRICS
SUP POLAR
CAUDAL PANCREATIC
RENAL IMPRESSION
CAUDATE PROCESS
CAUDATE LOBE
TUBERCLE
COMMON BILE DUCT
SUP TERMINAL
GASTRIC SURFACE
SUPRADUODENAL OF WILKIE
RIGHT LOBE
GASTRODUODENAL
INF TERMINAL
RT GASTRIC
DUODENUM
INF POLAR
RETRODUODENAL FORMING POSTERIOR PANCREATICODUODENAL ARCADE
INF SURFACE OF PANCREAS
LEFT GASTROEPIPLOIC
SUPERIOR PANCREATICODUODENAL FORMING ANTERIOR PANCRE ATICODUODENAL ARCADE
LARGE PANCREATIC
TRANS PANCREATIC
POST EPIPLOIC
INF PANCREATICO DUODENAL
LEFT EPIPLOIC
TRANSVERSE COLON
23 TERMINAL HEPATICS ENTER LIVER
UNCINATE BR
ANTERIOR EPIPLOIC
SUP MESENTERIC
LARGE EPIPLOIC ARC IN POSTERIOR LAYER OF GREAT OMENTUM
DORSAL PANCREATIC
JEJUNAL BRS
RT EPIPLOIC
RT GASTROEPIPLOIC

Figure 2



FIG 4 Photograph of a liver cast made by Healey and Schroy showing right segmental fissure (indicated by arrow) as seen when the right lobe is viewed from the right side It divides the right lobe into an anterior segment (which in the illustration is the upper one) and a posterior segment (the lower one in the illustration) (Compare with Figure 2 Healey and Schroy *Arch Surg* 66 599 1953)

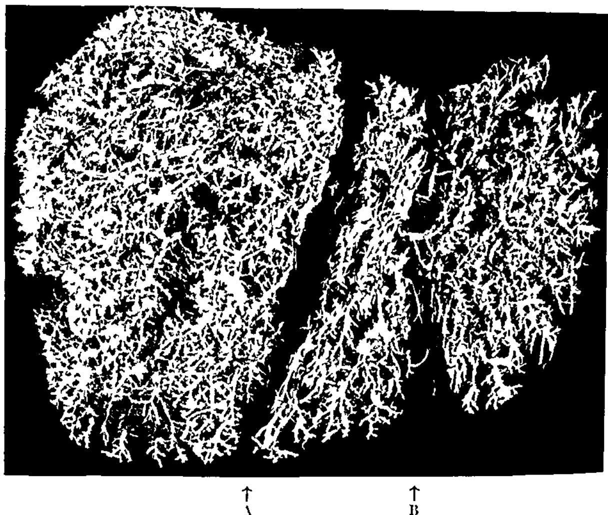


Fig 3 Photograph of a vinyl acetate cast of the human liver made by Healey and Schroy illustrating (A) the lobar fissure and (B) the left segmental fissure as seen from the parietal surface (Compare with Fig 1 Healey and Schroy *Arch Surg* 66 599 1953)

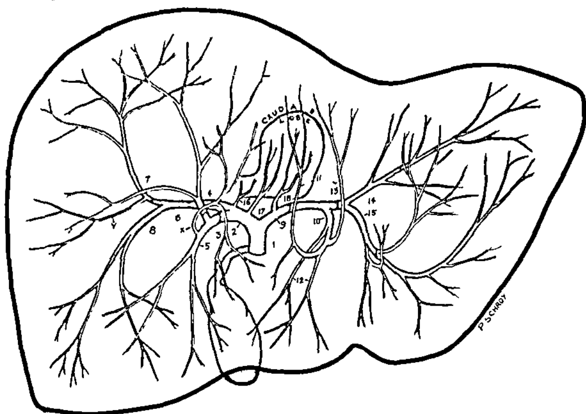


Fig 6A A composite drawing of the prevailing pattern of branching of bile ducts in the human liver (as illustrated by Healey and Schroy in Figure 4 *Arch Surg* 66 599 1953 and as augmented by Schroy in his Ph D thesis June 29 1953 entitled The Intrahepatic Distribution of the Bile Ducts within the Human Liver)

(1) Common hepatic duct (2) right hepatic duct (3) anterior segment duct (4) anterior superior area duct (5) anterior inferior area duct (6) posterior segment duct (7) posterior superior area duct (8) posterior inferior area duct (9) left hepatic duct (10) medial segment duct (11) medial superior area ducts (12) medial inferior area ducts (13) lateral segment duct (14) lateral superior area duct (15) lateral inferior area duct (16) caudate proces duct (17) right caudate lobe duct (18) left caudate lobe duct (x) fourth order duct draining area of Hjortsjo s ventrocranial segment (y) fourth order duct draining region within the angle formed by the posterior superior and the posterior inferior area ducts

According to Schroy y designates a portion of the posterior segment situated within the angle formed by the superior and the inferior area ducts characteristically drained by a relatively large fourth order bile duct This duct had its origin from the superior area duct in 95 casts (63 3 per cent) and from the inferior area duct in 44 casts (29 4 per cent) In the remaining 11 casts (7 3 per cent) the ducts to this region were double i e the smaller duct arose from each of the area ducts

According to Schroy x designates a group of fourth order ducts that drain an area of the anterior segment located subjacent to the summit of the anterior convexity of the parietal surface of the liver—an area designated by Hjortsjo as the ventrocranial segment The bile ducts draining this relatively small region were grouped together giving the appearance of an additional small segment capping the anterior segment which fact probably induced Hjortsjo to designate the region as a separate segment Since by definition all segments outlined in this study were drained by second order ducts this small group of fourth order ducts was considered a part of the anterior segment rather than a separate segment These statements of Schroy were supervised and verified by the author in an examination of samples

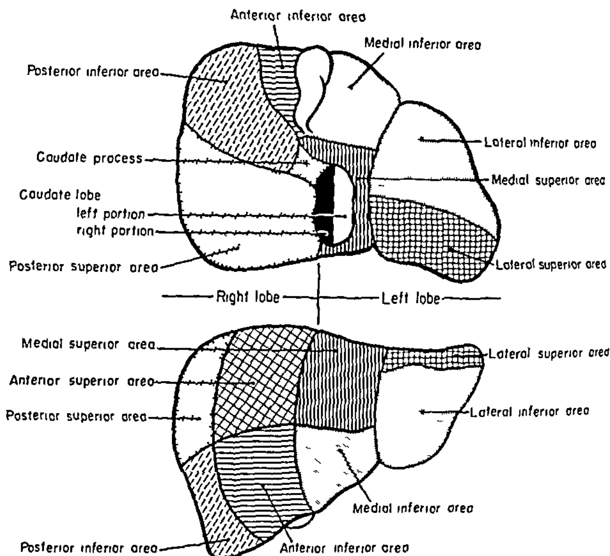


FIG 5 Division of the liver as based on the biliary and the arterial systems of the organ The upper drawing shows the visceral surface the lower drawing shows the parietal surface The right lobe has 2 segments anterior and posterior each with a superior and an inferior area The lateral and the medial segments of the left lobe have a superior and an inferior area (Redrawn with modifications in labeling and stippling from Fig 3 of Healey and Schroy *Arch Surg* 66 509 1953)

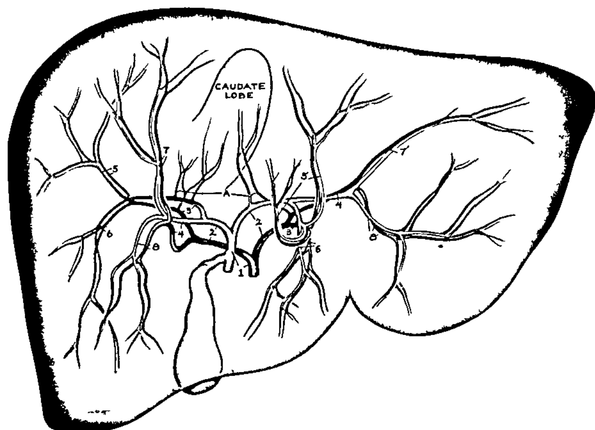


FIG 7 Composite drawing illustrating the prevailing pattern of branching of the hepatic artery and the common bile duct (1) Common hepatic artery and common bile duct (2) right hepatic artery and right bile duct (3) posterior segment artery and bile duct (4) anterior segment artery and bile duct (5) posterior superior area artery and bile duct (6) posterior inferior area artery and bile duct (7) anterior superior area artery and bile duct (8) anterior inferior area artery and bile duct

(2') Left hepatic artery and bile duct (3') medial segment artery and bile duct (4') lateral segment artery and bile duct (5') medial superior arteries and bile ducts (6') medial inferior arteries and bile ducts (7') lateral superior area artery and bile duct (8') lateral inferior area artery and bile duct (A) caudate lobe arteries (Compare with Figure 4 of Healey Schroy and Sorensen *J Internat Coll Surg* 20 133 1953 lettering altered by Healey and Schroy for A M.A exhibit in New York City in 1953 for which they were awarded a Certificate of Merit

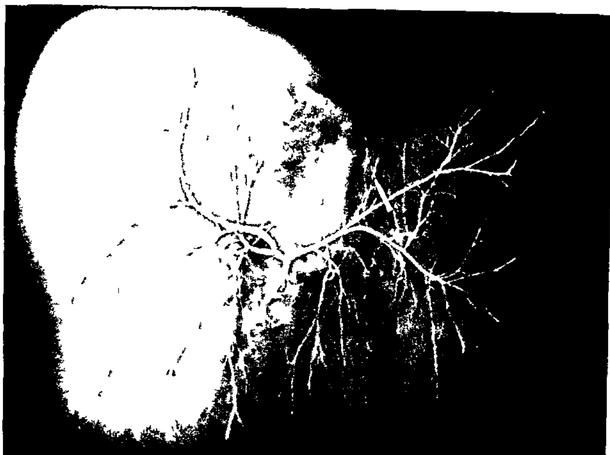
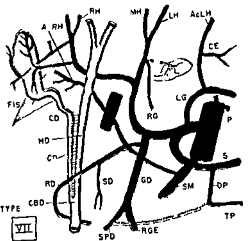
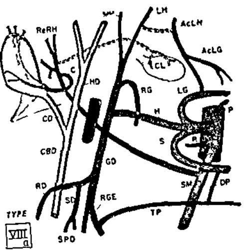
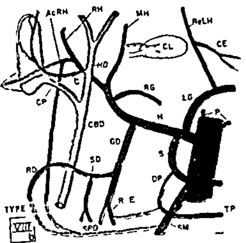
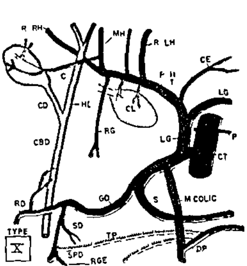


Fig 6B A cholangiogram of the human liver made by Healey and Schroy demonstrating the prevailing pattern of distribution of the intrahepatic ducts (anterior view contained in Schroy's thesis) Compare with the upper part of the illustration









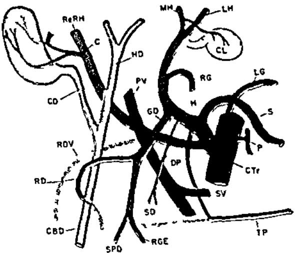
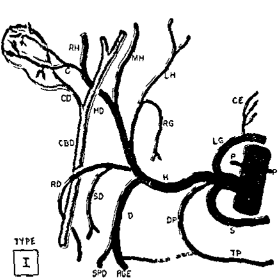
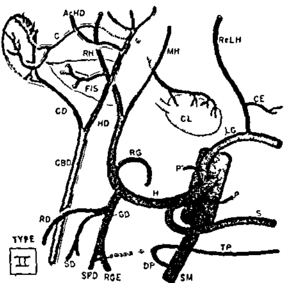
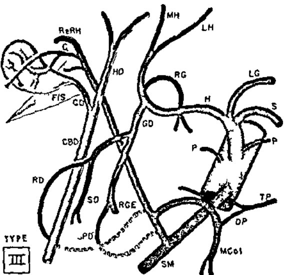
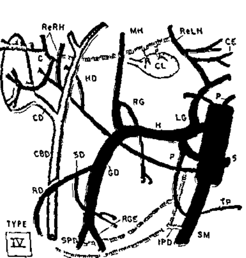


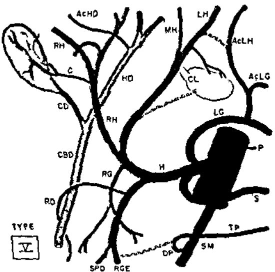
FIGURE 9 *(Caption and key to illustrations on pp 374 to 376)*











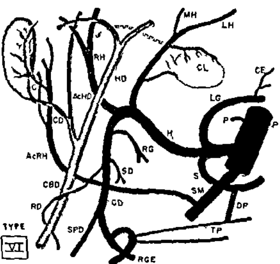


FIGURE 8 (Caption and key to abbreviations on pp 371–376)

(from the SM Type IX or the LG Type X)

The last illustration is inserted for the variant of a separate origin of the RH and of the LH from the CA is well worth remembering for in such instances the RH usually courses dorsal to the portal vein (PV) to reach the cystic triangle

When typical and complete the CA has 3 branches the LG the splenic (lienal) (S) and the H constituting a complete hepatolienogastric trunk (65% in 200 bodies) This trunk may be incomplete when the RH the MH or the LH arises from some other source thereby constituting an incomplete hepatolienogastric trunk) Hence in a complete or an incomplete form a hepatolienogastric trunk occurs in approximately 90% all other types of celiac trunks comprising the remaining 10% The CA may omit the LG forming a hepatolienal trunk (3 5%) or the H forming a lienogastric trunk (5 5%) or the S forming a hepatogastric trunk (1 5%)

Additive branches of the CA comprise the dorsal pancreatic (DP) (22%) the inferior phrenics (P) (74%) the middle colic (MCol) or an accessory middle colic (AcMCol) (3 cases) Frequently there is no celiac hepatic artery In this series the common H was replaced from the SM in 5 bodies from the aorta (A) in 3 bodies and from the LG in 1 body The tripod of Haller occurred in 25% a tetrapod (formed by the addition of the DP) in 5%

Aberrant hepatic arteries i e those arising otherwise than from a typical celiac hepatic comprise 2 types viz replaced and accessory the former being substitutive the latter additive vessels but only from the point of view of origin From a statistical analysis of the 200 bodies dissected in this study it may be concluded that in the general population an aberrant hepatic artery (replaced or accessory) occurs approximately in every other body (41 5%) and that 31 5% have but 1 aberrant hepatic artery while 10% have 2 or more

The terms accessory hepatic artery (ACH) and accessory hepatic ducts (AcHD) are de facto misnomers for functionally considered no hepatic artery or bile duct is accessory As plainly demonstrable in the 150 plastic casts of human livers made at the suggestion of the author at the Daniel Baugh Institute of Anatomy by Healey and Shroy each liver artery (aberrant or accessory) supplies a definite region of the liver just as Glauser of the University of Pennsylvania has shown that each small branch of the H supplies a definite pyramidal lobule of the liver Since the plastically injected arteries and bile ducts in the casts show no anastomosis (ANAS) between the right and the left lobes of the liver each vessel having its own area of functional significance it follows that surgically considered no liver artery or bile duct extrahepatically visible can be cut with impunity in the intact liver

Regarding the hepatic neoplasms Brunschwig calculated that up to 1953 there had been 570 resected cases of liver tumors While 80% of the dog s liver may be removed without fatal issue it is not known how much liver tissue may be removed from man The arterial patterns presented here should afford an anatomic guide as regards existent vascularization in the excision of metastatic malignant neoplasms in the liver and in complete right or left hepatic lobectomy

A	aorta
ACH	accessory hepatic artery
AcHD	accessory hepatic duct
AcLG	accessory left gastric artery
AcLH	accessory left hepatic artery
AcMCol	accessory middle colic artery
AcRH	accessory right hepatic artery
AE	anterior epiploic artery
ANAS	anastomosis
APS	arteria polaris superior
AS	anterior surface
ATI	arteria terminalis inferior
ATS	arteria terminalis superior
C	cystic artery
CA	celiac artery
CBD	common bile duct
CD	cystic duct
CF	cardio esophageal branches
CIPD	common inferior pancreatico-duodenal artery
Cl	caudate lobe
CP	caudal pancreatic artery
CTr	celiac trunk
DC	deep cystic artery
DP	dorsal pancreatic artery
F, Fis	fissured area
Fbr, FB, FBr, FBR	falciform branch

Figs 8 and 9 The Ten Basic Types of the Hepatic Arterial Blood Supply

The selective distribution of the hepatic arteries as shown in the following 10 basic types was ascertained by the author in 200 extrahepatic dissections made over a period of 6 years some of the drawings having been published in 1947 In a subsequent investigation jointly made at the Daniel Baugh Institute of Anatomy by Healey and Schroy on 150 vinyl acetate corrosion casts of human livers the selective distribution of the hepatic arteries was verified intrahepatically as follows

The RH *supplies the right lobe* composed of an anterior and a posterior segment each with a superior and an inferior area The LH supplies the lateral segment of the left lobe composed of a superior and an inferior area The MH supplies the medial segment of the left lobe composed of a superior and inferior area

The casts demonstrate that the quadrate lobe (QL) belongs to the left lobe as regards both its mode of vascularization and its biliary drainage The caudate lobe (CL) may receive blood vessels from either the RH or the LH or from both as depicted by the author in his drawings published in 1947 It may be drained by a bile duct which joins the right or the left branch or both branches of the hepatic duct as shown in extrahepatic dissections with vinyl injections of the ducts by Schroy in his M S thesis (1951) which preceded the intrahepatic verification of this fact in vinyl acetate corrosion casts by Healey and Schroy

An analysis of the 200 bodies dissected by the author in this study shows that in spite of the amazingly numerous variations in the blood supply of the liver any sample of the hepatic arterial pattern may with minor modifications be placed in one of the following basic types The drawings were made from dissected specimens and illustrate the manner in which (with 2 exceptions) the celiac (CA) supplies the following types

Type I The right the left and the middle hepatic (textbook type and present in only about half of the subjects (55% M W 71 yrs)

Type II The right and the middle hepatic the left hepatic replaced from the left gastric (10% F W 65 yrs)

Type III The left and the middle hepatic the right hepatic replaced from the superior mesenteric (11% M W 73 yrs)

Type IV Only the middle hepatic the right hepatic replaced from the superior mesenteric the left hepatic replaced from the left gastric (1% M W 78 yrs)

Type V The right the middle and the left hepatic, the left gastric is double one being an accessory left hepatic from the left gastric (8% M W, 39 yrs)

Type VI The right the middle and the left hepatic the right hepatic is double one being an accessory right hepatic from the superior mesenteric (7% M W 60 yrs)

Type VII The right the left and the middle hepatic in addition there is an accessory right hepatic from the superior mesenteric and an accessory left hepatic from the left gastric (1% F N 53 yrs)

Type VIII Combination patterns (a) of a replaced right hepatic and an accessory left hepatic (M W 69 yrs) and (b) of an accessory right hepatic with a replaced left hepatic (2% M N adult)

Type IX The celiac hepatic is absent the entire hepatic trunk is derived from the superior mesenteric (4 5% M N 46 yrs)

Type X The celiac hepatic is absent the entire hepatic trunk is derived from the left gastric (Fig 123 1 case) (M N adult)

Variant The celiac hepatics are double the right hepatic arising from the proximal the left hepatic from the distal end of the celiac

The mode of formation of 4 of the 10 basic types having a replaced hepatic can be explained readily as follows Typically after giving off the gastroduodenal (GD) the hepatic (H) divides into the RH the MH and the LH the MH (for the medial segment or QL) being a branch of either the RH or the LH extrahepatically considered (Type I) When the H divides into the GD and the RH (the latter with the MH) the LH is replaced by an artery from the left gastric (LG) (Type II) When the H divides into the GD and the LH (the latter with the MH) the RH is replaced by an artery from the superior mesenteric (SM) (Type III) When the H divides into the GD and the MH both the RH and the LH are replaced (Type IV)

The mode of formation of types with an accessory hepatic artery (ACH) is self evident for an ACH (from the standpoint of origin) occurs only in conjunction with a typical RH or LH in some instances both RH and LH being present (Type VIII) The remaining 2 basic types comprise cases where the entire hepatic trunk is replaced

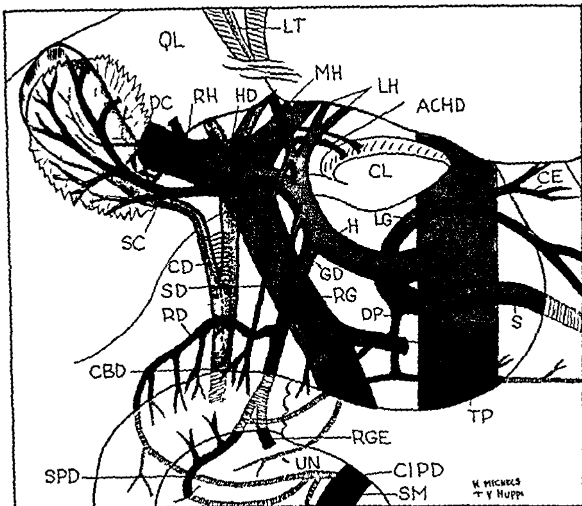


Fig 10 Typical textbook pattern with 3 hepatic arteries (H) given off by a celiac hepatic which arises from a complete hepatolienogastric celiac trunk (CTr) This type is present in only about one half of the population in this series of 200 bodies in 55% Two cystic arteries (C) (gemellae cysticae of Vesalius) An accessory left hepatic duct (F W 38 yrs)

The H after giving off the gastroduodenal (GD) divides into a right a middle and a left branch the middle hepatic (MH) for the quadrate lobe (QL) As is frequently the case (25%) there are 2 cystic arteries (C) the superficial cystic (SC) being distributed to the peritoneal free surface the deep cystic (DC) to the nonperitoneal attached surface of the gallbladder (GB) and the underlying liver substance The supraduodenal artery of Wilkie (SD) is distributed to the upper the anterior and the posterior surfaces of the first inch of the duodenum Here it is very long arising high from the MH

The retroduodenal (RD) arises as the first branch of the GD crosses the conjoined cystic (CD) and hepatic (HD) ducts anteriorly then forms an extensive posterior pancreaticoduodenal arcade on the back of the duodenum the head of the pancreas and the common bile duct (CBD) The anterior pancreaticoduodenal arcade is made by the superior pancreaticoduodenal (SPD) and lies more caudad Both arcades unite with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (CIPD) The dorsal pancreatic (DP) has a typical origin from the first part of the splenic (S) It courses downward near the junction of the splenic vein (SV) with the superior mesenteric vein (SMV) to become distributed to the dorsal surface of the neck of the pancreas its prominent left branch is the transverse pancreatic (TP) running along the inferior surface of the pancreas at the tail end of which it unites with terminal branches of the S Its small right branch joins the SPD another branch supplies the uncinate process of the pancreas The CD is very long (6 cm) and of the parallel type Coursing with the HD to which it is bound for 4 cm it swerves posteriorly to it to open in the CBD just above the duodenum

An accessory left hepatic duct (AcHD very rare) drains the caudate lobe (CL) CD 6 cm HD 7 cm CBD 2 cm

GB gallbladder
GD gastroduodenal artery

H hepatic artery
HD hepatic duct
HV hepatic vein

IP inferior polar artery
IPD inferior pancreaticoduodenal artery
IS inferior surface of gallbladder
IT inferior terminal artery
IVC inferior vena cava

J jejunal branch

LCol left colic artery
LE left epiploic artery
LG left gastric artery
LGE left gastro-epiploic artery
LH left hepatic artery
LIP left inferior phrenic artery
LN lymph node of Luschka (ganglion of Terrier)
LT ligamentum teres
LV ligamentum venosum

MCol middle colic artery
MH middle hepatic artery

P inferior phrenic artery
P pyloric branch
PD pancreatic duct
PE posterior epiploic artery
PM a pancreatica magna
PTr a pancreatica transversa
PV portal vein

QL quadrate lobe

RD retroduodenal artery (posterior superior pancreaticoduodenal)
RDV retroduodenal vein
RE right epiploic artery
ReH Tr replaced hepatic trunk
ReLH replaced left hepatic artery
ReRH replaced right hepatic artery
RG right gastric artery
RGE right gastro-epiploic artery
RH right hepatic artery
RI renal impression
RIL right inferior lobular branch
RIP right inferior phrenic artery
RR right renal artery

S splenic artery (lienal)
SC superficial cystic artery
SD supraduodenal artery of Wilkie
SG short gastrics
SM superior mesenteric artery
SMV superior mesenteric vein
SP superior polar artery
SPD superior pancreaticoduodenal artery (anterior)
ST superior terminal artery
SV splenic vein

TO tuber omentale
TP transverse pancreatic artery (inferior pancreatic)
TrCol transverse mesocolon

Un uncinate process

(Drawings I II III V VI IX were made by Gloria Green Hirsch published in Morris Human Anatomy ed 11 Fig 535 from McGraw Hill Blakiston Division the others were made by Vincent Nast)

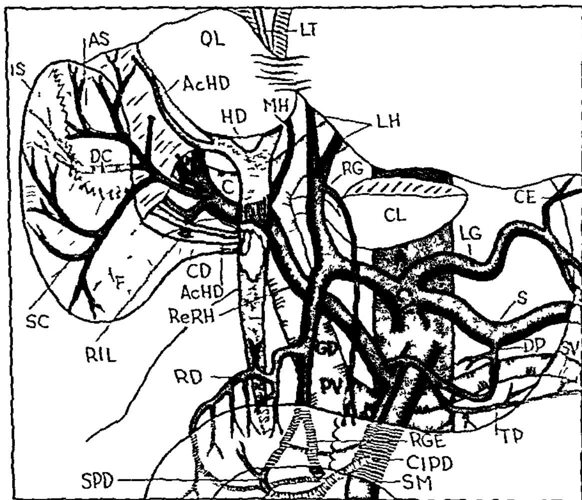


FIG 12. Type with a replaced right hepatic (ReRH) from the superior mesenteric (SM) as the celiac hepatic gives rise only to the gastroduodenal (GD) and the left hepatic (LH) Incidence 11% Two accessory hepatic ducts (AcHD) Single cystic (M W 74 yrs)

As frequently is the case the hepatolienogastric celiac trunk (CTr) is *incomplete* the right hepatic (RH) being supplied by the SM Constituting the *only blood supply to the right lobe* the RH from the SM is not an accessory hepatic (ACH) but a replaced one (ReRH) It gives off the middle hepatic (MH) for the quadrate lobe (QL)

In its ascent to the cystic triangle of Calot the ReRH crosses the hepatic duct (HD) close to its junction with the cystic duct (CD) The branch which it gives off to the fissured area (F) under the gallbladder (GB) could be mistaken for the cystic (C) which arises immediately above it. The C lies high and is situated precariously between 2 AcHD

The common bile duct (CBD) is supplied by a branch from the retroduodenal (RD) as the latter crosses it anteriorly above the duodenum. The transverse pancreatic (TP) takes origin from the ReRH instead of the SM and is anastomosed with the dorsal pancreatic (DP) which arises from the splenic (S) The anterior and the posterior pancreaticoduodenal arcades unite with the SM via a common inferior pancreaticoduodenal (CIPD) The CD is short and stubby running close to and parallel with it is a large AcHD (4 mm) which has its opening adjacent to or in common with, that of the CD *Coming from the GB bed is another AcHD (1 mm)* the subvesical duct, which joins the right branch of the HD Both AcHD are liable to injury during cholecystectomy the lower could be cut, the upper torn during removal of the GB causing discontinuing postoperative leakage of bile CD 2 cm HD 2.5 cm CBD 6 cm

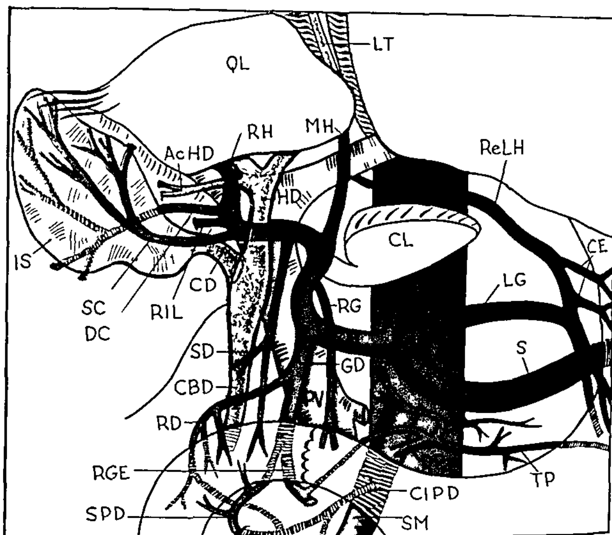


FIG 11 Type with a replaced left hepatic (ReLH) from the left gastric (LG) as the celiac hepatic here gives origin only to the right hepatic (RH) and middle hepatic (MH) Incidence 10% Two cystic arteries An accessory hepatic duct (AcHD) (M W 78 yrs)

The artery supplying the left lobe of the liver *is not an accessory hepatic (ACH) as commonly stated but is one definitely replaced by the LG* To prevent necrosis such a left hepatic (ReLH) should never be sacrificed in a gastric resection since it is the *only blood supply* to the left lobe excepting in some instances a few twigs from the MH in its course along the peripheral edge of the lesser omentum it gives off cardio esophageal branches (CE)

The cystic artery (C) is double for as is often the case (25%) its superficial (SC) and deep branch (DC) have a separate origin Interposed between them is a liver artery (right inferior lobular RIL) which could be mistaken for a C

The supraduodenal (SD) is a branch of the RH in its long descent to the first inch of the duodenum which it supplies it gives off branches to the common bile duct (CBD) a fact to be remembered in explorations of the common duct lest by removing this supply the duct become necrosed Instead of coming from the celiac trunk (CTr) or one of its branches (first part of the splenic S or the hepatic H) the dorsal pancreatic (DP) arises from the superior mesenteric (SM) To the right it communicates with the right gastro epiploic (RGE) to the left it gives off its transverse pancreatic branch (TP) upward it sends branches to the dorsal surface of the neck of the pancreas a typical pattern of its distribution At the junction point of the short cystic duct (CD) there is an ampullation of the hepatic duct (HD) a frequent phenomenon Above the DC is an AcHD Coming from the gallbladder (GB) region this *subvesical duct* may be mistaken for a nerve or a connective tissue strand and thus readily be torn in cholecystectomy with resultant postoperative jaundice CD 1 cm HD 3 cm CBD 8 cm

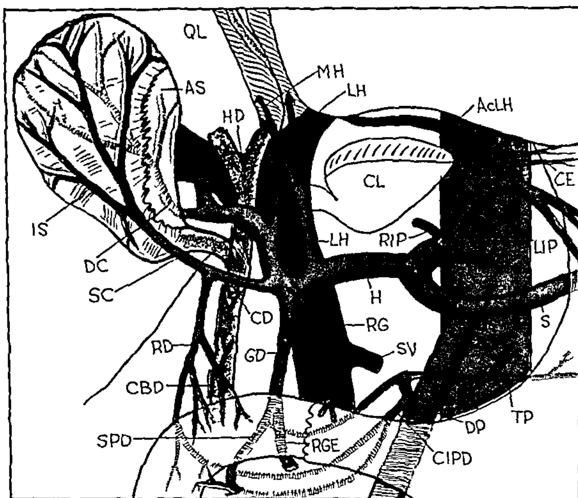


FIG 14 Type with an accessory left hepatic (AcLH) from the left gastric (LG) plus 3 hepatics (right RH middle MH left LH) from the celiac hepatic Incidence 8% Double cystic artery (C) the superficial cystic (SC) arising from the gastroduodenal (GD) via its retroduodenal (RD) branch (M N adult)

The celiac hepatic gives off its characteristic 3 branches RH MH and LH Since the celiac LH is small there is an AcLH from the LG (13%) it being accessory only in origin since it supplies a definite section of the left lobe The RH is ventral to the hepatic duct (HD) a relation occurring in 10% to 20% of the population in this series of 200 bodies purely ventral crossings were observed in 12%

Of the dual variety of cystics (C) this is a fairly common pattern The deep cystic (DC) arises in Calot s triangle from a caterpillarlike loop of the RH and is distributed to the attached surface of the gallbladder (GB) and the GB bed the SC takes origin from the GD via its RD branch courses caudal to the cystic duct (CD) and is distributed to the free peritoneal surface of the GB In some instances the entire C may arise from the GD or from its retroduodenal branch with similar orientation in course *That a C may be given off by an intestinal artery (GD RD SPD SM) should always be borne in mind for ordinarily the surgeon does not look for a C caudal to the CD* In a case similar to the one shown the point of ligation of the SC should be chosen properly lest the blood supply to the back of the duodenum be taken with resultant necrosis

The dorsal pancreatic (DP) arises from the superior mesenteric (SM) In addition to its characteristic transverse pancreatic branch (TP) it has the common inferior pancreaticoduodenal (IPD) a branch ordinarily supplied by the SM The CD swerves to the posterior surface of the HD with which it is united intimately with connective tissue for 1 5 cm Its opening lies below the SC CD 3 cm HD 5 cm CBD 6 cm

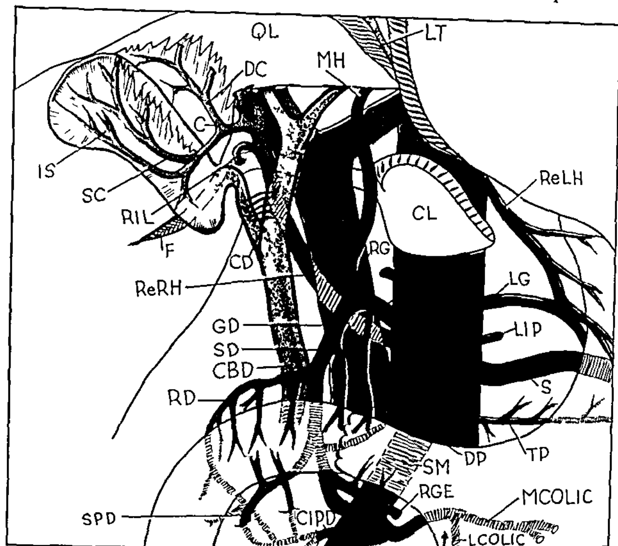


Fig 13 Type with a replaced right hepatic (ReRH) from the celiac axis the replaced left hepatic (ReLH) from the left gastric (LG) as the celiac hepatic divides only into the gastroduodenal (GD) and the middle hepatic (MH) the latter for the quadrate lobe (QL) Incidence 1% Single cystic Mid dle colic anastomosed with the right gastro epiploic artery (RGE) (F N 62 yrs)

When an *ReRH* comes from *the* celiac trunk (CTr) instead of the superior mesenteric (SM) as here it usually passes *behind* the portal vein (PV) In its ascent to the cystic triangle of Calot it lies close to the junction point of the cystic (CD) and the hepatic ducts (HD) where it is subject to surgical harm The cystic artery (C) lies high and is short dividing nearly immediately into its superficial (SC) and deep branches (DC) *A liver branch (RIL) of the ReRH in the cystic triangle to the fissured area (F) under the gallbladder (GB) may be mistaken for the C when exposed by needless excessive probing through overlying omental tissue*

Origin of the dorsal pancreatic (DP) with its transverse pancreatic branch (TP) is shifted to the SM a frequent pattern Note the large anastomosis (ANAS) between the right gastro-epiploic (RGE) and the middle *colic (MCol) thus making feasible* a col lateral circulation via the celiac (CA) or the SM when either of these vessels becomes occluded A comparable anastomosis is often effected via a descending branch of the DP when the latter arises from the CA The supraduodenal (SD) arises from the right *side of the gastroduodenal (GD) as is* commonly the case The anterior and the posterior pancreaticoduodenal arcades unite with the SM via a common inferior pancreaticoduodenal (IPD) The inferior phrenics (RIP LIP) arise separately and at different levels from the aorta (A) The CD is bound intimately to the HD for a short stretch (short parallel type) before opening into it a fact to be remembered lest the common duct be injured as is so often experienced *CD 3* cm *HD 3* cm *CBD* 6 5 cm

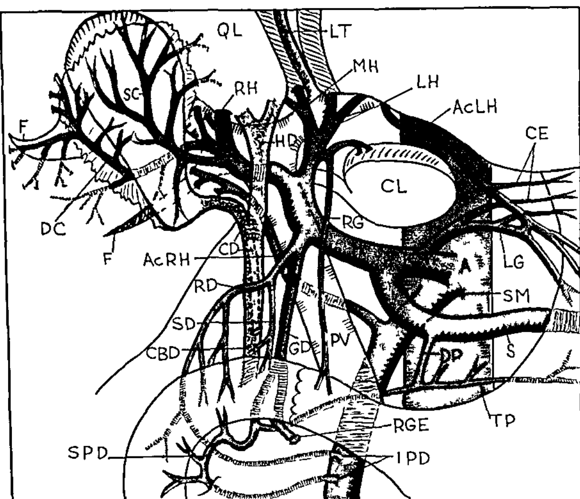


FIG 16 Type with an accessory right hepatic (AcRH) from the superior mesenteric (SM) and an accessory left hepatic (AcLH) from the left gastric (LG) plus 3 typical hepatic branches (right RH middle MH and left LH) from the celiac hepatic Incidence 1% Double cystic artery (F N 52 yrs)

Here the hepatic blood supply is effected by 5 major liver arteries coming from 3 different sources viz the celiac (CTr) the SM and the LG

The AcRH derived from the SM proceeds upward behind the portal vein (PV) It presents a surgical hazard while crossing the hepatic duct (HD) and coursing close to the cystic duct (CD) As is typically the case it supplies the fissured area (F) under the gall bladder (GB) with several branches *any one of which may be mistaken for the cystic (C)* In some instances a comparably disposed AcRH gives off a cystic artery the entire cystic its superficial or deep branch The dual cystics here arise from the RH nearly at the same point The deep cystic (DC) after giving a branch to the liver and after supplying the attached surface of the gall bladder (GB) *is prolonged beyond the confines of the latter into a fissure (F) as a liver artery* a possibility to be thought of and checked when removing the GB lest by severance of such an artery a necrotic area becomes established

The anterior and the posterior pancreaticoduodenal arcades unite with the SM via a separate inferior pancreaticoduodenal (IPD) The dorsal pancreatic (DP) shows a typical origin from the splenic (S) and its division into right and left (transverse pancreatic TP) branches The cardio esophageal region is supplied copiously by branches (CE) from the AcLH and the LG The long (6 cm) parallel type of CD courses behind the HD (7 5 cm) to which it is tied for 3 5 cm and opens posteriorly above the duodenum *Because of its contiguity with the HD the latter may be injured readily in cholecystectomy often at a relatively high level* CD 6 cm HD 7 5 cm CBD 3 5 cm

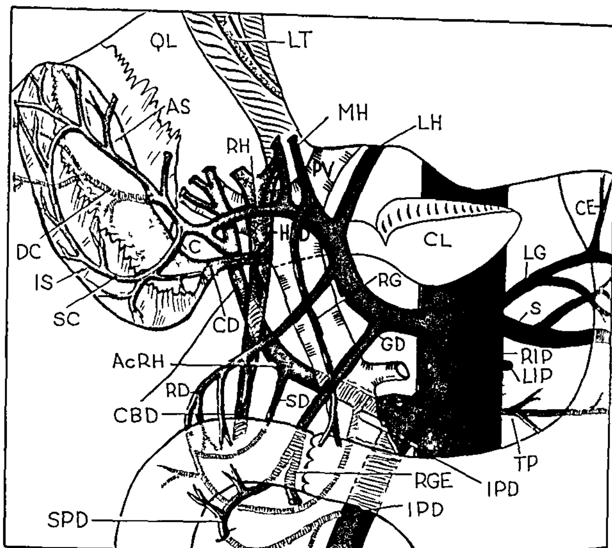


FIG 15 Type with an accessory right hepatic (AcRH) from the superior mesenteric (SM) as the celiac (CA) gives off a left (LH) a middle (MH) and a right hepatic (RH) branch Incidence 7% Single cystic Anastomosis (ANAS) between the RH and the AcRH (M W 44 yrs)

Since the celiac RH *gives off only the cystic (C) and a very small liver branch an AcRH from the SM supplies the right lobe the artery being accessory however only in origin* The anastomosis here between the 2 RH over the hepatic duct (HD) necessitates careful inspection to avoid injury to the duct and bleeding The anastomosis establishes a collateral route whereby blood from the SM may reach the terminal hepatic branches when the CA becomes occluded

Surgically considered the C could be ligated at 3 points (1) before it crosses the HD at which point it is still the RH (2) at the anastomotic channel between the AcRH and the RH (to the right of the letter C) or (3) just before it divides into its superficial (SC) and deep branches (DC) (above the letter C) the latter only being the proper procedure

The retroduodenal (RD) *is a branch of the hepatic (H)* and not as usual a branch of the gastroduodenal (GD) thereby justifying its specific nomenclature As it descends anterior to the common bile duct (CBD) it supplies the latter then swerves posteriorly to form an arcade on the back of the duodenum the head of the pancreas and the CBD the arcade here uniting with the AcRH via its own inferior pancreaticoduodenal (IPD) The supraduodenal (SD) is a branch of the AcRH and is definitely anastomosed with the RD a conclusive proof that it is not an end artery as claimed by Wilkie Odd origin of the transverse pancreatic (TP) for here it springs from the AcRH instead of the SM Right gastric (RG) arises high from the MH The short angular type cystic duct (CD) joins the common HD anteriorly and to the left It is dangerously close to the underlying AcRH and to the anastomotic channel CD 4 cm HD 4 cm CBD 6 5 cm

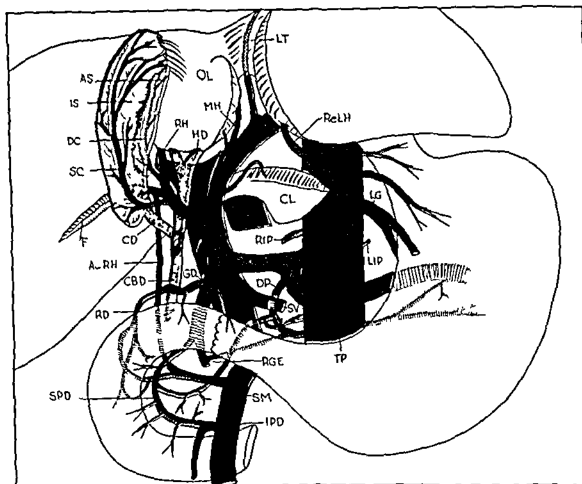


FIG 18 Combination pattern (*b*) (the reverse of combination pattern *a* Fig 17) with an accessory right hepatic (AcRH) from the superior mesenteric (SM) and a replaced left hepatic (ReLH) from the left gastric (LG) the celiac hepatic supplying the right hepatic (RH) with a middle hepatic branch (MH) Incidence 1% Double cystic artery (M N adult)

The entire left lobe in this combination pattern is supplied by a hepatic (ReLH) stemming from the LG The latter here is in reality *a gastrohepatic artery a term first used by Haller (1756) and still employed in French texts*

Here the arteries traversing the cystic triangle have a hazardous arrangement and require careful inspection and checking There are 2 cystics (C) the point of origin of the superficial (SC) and the deep cystic (DC) being so close as to simulate one cystic The large artery entering the fissured area (F) (1 cm long) under the gall bladder (GB) readily could be mistaken for the C when exposed by excessive probing The sample presented warrants the admonition that *an artery that looks like a C and courses near and parallel with the cystic duct (CD) is not necessarily the C (Cole)* It may be a large liver artery which here most probably is the *posterior segmental branch* Surgically considered an artery of this kind could be severed at the site of its origin from the RH or distal to the point where it is anastomosed to the AcRH derived from the SM In either case the right lobe would be deprived of a large part of its blood supply with disconcerting postoperative results including necrosis and death (Gordon Taylor Cole)

The retroduodenal arcade (RD) communicates with the AcRH which at the site of its origin from the SM functions as the arcade s inferior pancreaticoduodenal (IPD) The dorsal pancreatic (DP) (4 mm) is typical presenting a left branch (transverse pancreatic TP) and 2 right branches the upper joining the right gastro-epiploic (RGE) the lower constituting the uncinate branch which unites with the superior pancreaticoduodenal (SPD) The CD is of the angular type and is here closely related to the underlying AcRH CD 3 cm HD 3 5 cm CBD 6 cm

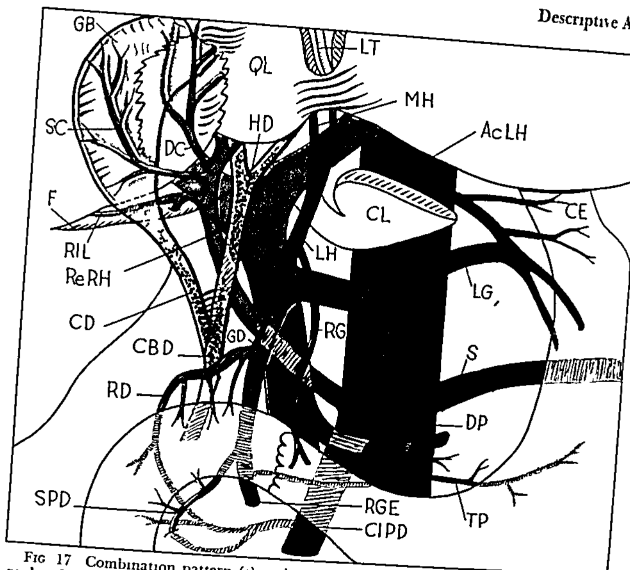


FIG 17 Combination pattern (*a*) with a replaced right hepatic (ReRH) from the superior mesenteric (SM) and an accessory left hepatic (AcLH) from the left gastric (LG) the celiac hepatic giving origin to a left hepatic (LH) with a middle hepatic branch (MH) Incidence 1% Double cystic artery (M N adult)

The right hepatic (ReRH) is replaced i e takes origin from the SM which here gives off the splenic (S) constituting a hepatolienomesenteric trunk incidence of which is very rare In its course to the cystic triangle the ReRH passes under then over the portal vein (PV) and is dangerously close to the junction point of the cystic duct (CD) and the hepatic duct (HD) Before giving rise to the dual cystics *it sends a branch (RIL) probably the posterior segmental branch to the fissured area (F) under the gallbladder (GB) which when exposed by excessive probing of omental tissue may be mistaken for the cystic (C)* The site of origin of the 2 cystics is nearly contiguous the deep cystic (DC) supplying liver twigs (medial to the GB) which when not properly tied off may cause profuse and annoying bleeding

The anterior and the posterior pancreaticoduodenal arcades respectively made by the retroduodenal (RD) and the superior pancreaticoduodenal (SPD) unite with the SM via a common inferior pancreaticoduodenal (IPD) The dorsal pancreatic (DP) arises from the first part of the S near the site of junction of the S with the superior mesenteric vein (SMV) and presents its 3 typical branches to wit branches to the back of the neck of the pancreas a right branch which joins the right gastro-epiploic (RGE) and a left branch (the transverse pancreatic TP) which courses along the inferior surface of the pancreas The CD is long (5 cm) and is united for a stretch with the HD thus placing its opening caudad to point at which it comes in contact with the HD In freeing the CD such an anatomic arrangement should always be borne in mind lest the HD be injured become obstructed or actually be severed in the latter case necessitating a reconstruction of the common duct CD 5 cm HD 5 cm CBD 5 cm

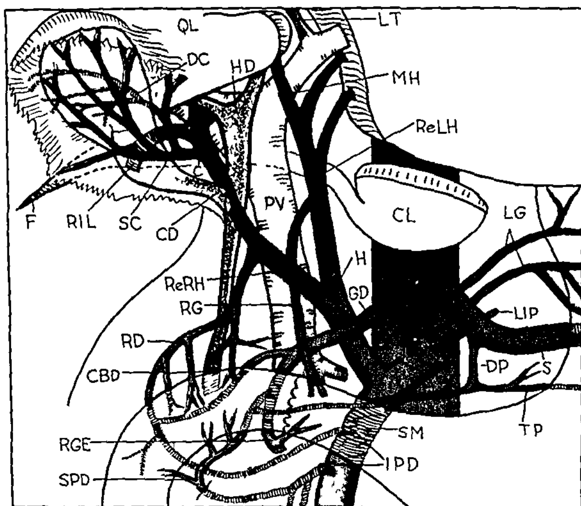

QL
LT
DC
HD
MH
ReLH
C
F
RIL
SC
CD
PV
CL
LG
H
ReRH
GD
RG
LIP
RD
DP
S
CBD
TP
SM
RGE
IPD
SPD

FIGURE 19

FIG 19 Type without a celiac hepatic The entire blood supply to the liver comes from the superior mesenteric (SM) via a replaced common hepatic trunk (H) which gives rise to the right (RH) the left (LH) and the middle hepatic (MH) branches *Incidence 2 5% Hepatomesenteric trunk* Single cystic (M W 36 yrs)

In contrast with the frequent origin of a RH from the SM is the mode of origin of the *entire common hepatic* from the SM as presented here only 5 cases having been observed in 200 bodies A hepatomesenteric artery has a varied anatomy Not only may it supply an accessory (AcRH) or a replaced right hepatic (ReRH) but also in some instances it gives rise to the *entire hepatic trunk* This fact should be remembered in *every pancreaticoduodenal resection for the common hepatic may pass through the head of the pancreas (Fig 38) and because of this relationship inadvertently become severed during the operation with the resultant immediate death of the patient*

The replaced common hepatic trunk (ReHTr) need not necessarily give off the gastroduodenal (GD) for here the latter *arises separately from the celiac* (CA) along with the splenic (S) and 2 left gastrics (LG) forming thereby a lienogastro gastroduodenal celiac trunk (CTr) Note the low origin of the 2 LG

The single cystic (C) has a very short stem and is closely related to a large liver branch (right inferior lobular RIL) distributed to the fissured area (F) under the gallbladder (GB) the fissure being covered i e packed with lesser omentum tissue The inexcusable ligation of such a large branch of the RH during cholecystectomy would deprive the right lobe of a major part of its blood supply and readily may be the direct cause of grave morbidity and death as stated by Gordon Taylor and others

The retroduodenal arcade (RD) here is double the upper unites with the GD the lower with the SM via its own inferior pancreaticoduodenal (IPD) The anterior pancreaticoduodenal arcade communicates with the dorsal pancreatic (DP) and has its own IPD which typically arises from the SM caudad to the IPD of the posterior arcade

Attachment of the GB 2 cm wide 4 5 cm long The opening of the *cystic duct* (CD) was anterolateral CD 3 cm HD 3 cm CBD 6 cm

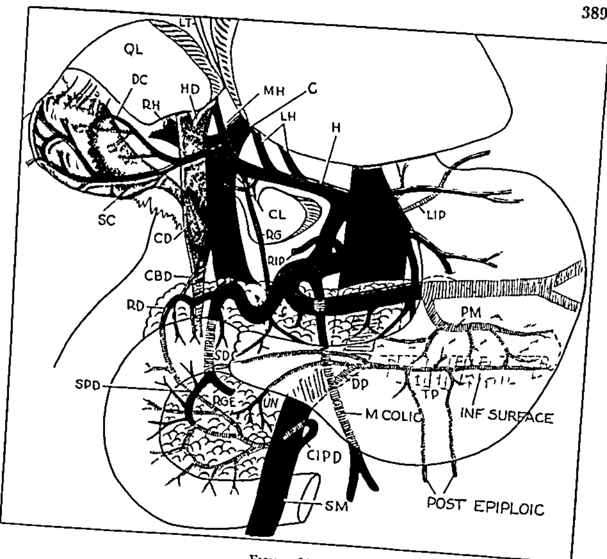

LT
QL
DC
HD
RH
MH
C
LH
H
CL
SC
CD
RG
LIP
RIP
CBD
RD
PM
SD
SPD
DP
RGE
UN
TP
M COLIC
INF SURFACE
CIPD
SM
POST EPIPLOIC

FIGURE 20

FIG 20 Type with the common hepatic artery (H) derived from the left gastric (LG) Gastroduodenal (GD) and middle colic (MCol) from the celiac trunk (CTr) One case in 500 bodies Single cystic (M N 85 yrs)

This odd case made possible the classification of the hepatic blood supply into 10 types Here the entire blood supply to the liver comes from the LG via a replaced common H Seen once in approximately 500 bodies it occurs very rarely In preliminary dissection *no trace* of the H was discernible Eventually it was found at the peripheral edge of the lesser omentum largely hidden by the liver In its course to the right it gave off the left hepatic (LH) the middle hepatic (MH) and the right hepatic (RH) the caudate branch and the cystic (C) which arose from the MH In gastric resections such an anomalous common hepatic *from the LG could be severed readily along with the LG with resultant immediate death of the patient*

Surgically considered it is extremely important to know that the MCol or *a large accessory middle colic* (AcMCol) may take origin from the CTr Here the artery is actually the MCol When an AcMCol has this origin it supplies the distal end of the transverse colon and the upper section of the descending colon and it communicates with the left branch of the MCol at one end and with the left colic (LCol) from the inferior mesenteric at the other end

The dorsal pancreatic (DP) instead of coming from the SM here springs from the MCol and gives off its 3 characteristic branches to the left the transverse pancreatic (TP) which unites with the a pancreatica magna (PM) from the splenic (S) and which sends slender posterior epiploic branches to the transverse mesocolon (Tr Col) to the right a branch which joins the GD another which supplies the uncinate process of the pancreas (Un)

The C arises from the MH to the left of the hepatic duct (HD) After crossing the latter anteriorly it quickly divides into its superficial (SC) and deep branches (DC) *The supraduodenal (SD) is a short branch* of the GD The retroduodenal (RD) crosses the supraduodenal portion of the common duct (CBD) and is subject to injury during explorations of the duct. The anterior and the posterior pancreaticoduodenal arcades end in a common inferior pancreaticoduodenal (IPD) which here springs from the left side of the superior mesenteric (SM) a point to be noted in resections

Branches of the left inferior phrenic (LIP) supply the esophagus The cystic duct (CD) swerves posteriorly *to the HD* and opens into it after having made a one-quarter spiral The CBD tapers in its descent as is frequently the case CD 4 cm HD 4 5 cm CBD 4 cm

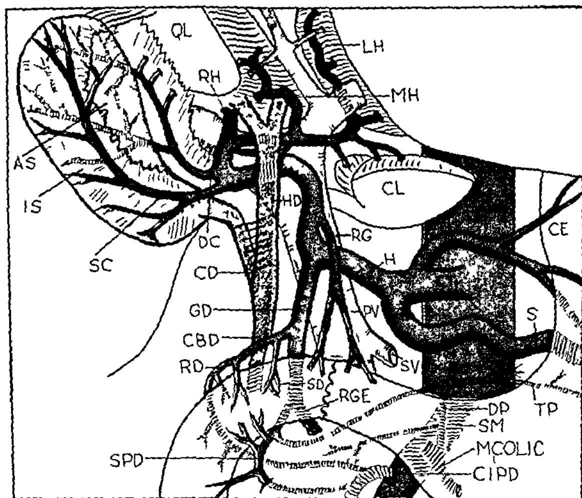


FIG 22 Very odd mode and site of origin of the middle hepatic (MH) and the left hepatic (LH) from the hepatic (H) namely *to the right of the hepatic duct (HD)* deep in the porta hepatis (seen but once in 500 bodies) (M W 74 yrs)

Characteristic caterpillarlike downward loop made by the right hepatic (RH) in the *cystic triangle of Calot* The superficial (SC) and the deep (DC) cystics arise nearly *from the same point at the summit of the loop* The middle colic (MCol) gives off the dorsal pancreatic (DP) *which in* turn supplies the transverse pancreatic (TP) to the left and 2 branches to the right one of which unites with the superior pancreaticoduodenal (SPD) the other supplies the uncinate process of the pancreas The caudate lobe (CL) *is supplied* by the left hepatic

Huge gallbladder (GB) 9 cm long 5 cm wide with attachments of the same *dimensions Short* parallel *cystic duct* (CD) tied to the HD for 1 5 cm CD 4 *cm HD 6 cm* CBD 6 cm

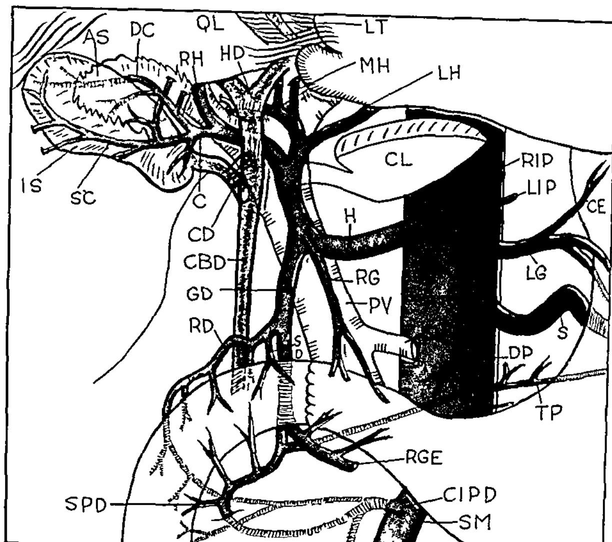


Fig 21 Separate origin of the hepatic artery (H) from the aorta (A) (4 cases in 200 bodies) Lienogastric trunk Single cystic (F W adult)

Typical textbook pattern of the origin of the cystic artery (C) from the right hepatic (RH) in Calot's triangle *but a very atypical separate origin of the hepatic trunk from the A* and a separate origin of the splenic (S) and the left gastric (LG) from the A via a common lienogastric trunk Thereby *the blood supply to the supracolonic organs was effected by 2 entirely different main routes the hepatic taking care of the liver the duodenum and the head of the pancreas and the lienogastric trunk supplying the left side i e the stomach the spleen and the body and the tail of the pancreas*

The dorsal pancreatic (DP) arose from the first part of the S Upon reaching the *inferior border of the pancreas* it gave off the transverse pancreatic (TP) to the left and a branch to the right that communicated *with the superior pancreaticoduodenal* (SPD) A common inferior pancreaticoduodenal (CIPD) from the *superior mesenteric (SM)* received the anterior and the posterior pancreaticoduodenal arcades made respectively by the SPD and the *retroduodenal (RD)* The supraduodenal (SD) to the first part of the duodenum was a branch of the RD as is frequently the case

The attachment of gallbladder (GB) was 5 cm long 2 cm wide Its distal end was free (2 5 cm) The cystic duct (CD) was tied to the hepatic duct (HD) for 1 5 cm before opening CD 3 cm HD 3 5 cm CBD 6 cm

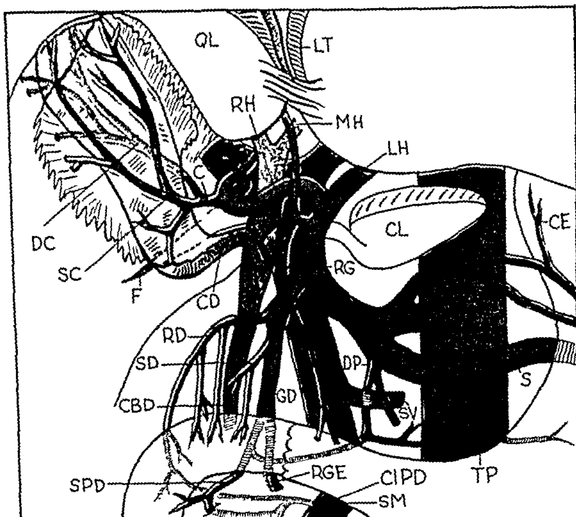


FIG 24 Typical *caterpillarlike loop* made by the right hepatic (RH) to the right and into Calot's triangle after it crossed the hepatic duct (HD) anteriorly Single cystic (M W 58 yrs)

The RH frequently lies *ventral to the HD* (14%) The stem of the cystic (C) is very short the artery dividing nearly immediately into its superficial (SC) and deep branches (DC) these being the gemellae cysticae of Vesalius The right gastric (RG) and the middle hepatic (MH) arise via a common trunk from the hepatic artery (H) proper The supraduodenal (SD) in its descent to the first part of the duodenum supplies the common bile duct (CBD) *Injury to this artery may cause necrosis of the common duct* (Appleby) The dorsal pancreatic (DP) exhibits a common pattern one branch passes anterior to the splenic vein (SV) the other passes dorsal to it and gives rise to the transverse pancreatic (TP) to the left and a branch to the right after passing dorsal to the superior mesenteric vein (SMV) anastomoses with the superior pancreaticoduodenal (SPD)

The cystic duct (CD) opens anteriorly *and to the left* In this case Hartmann's pouch of the gallbladder (GB) overlaid the cystic triangle CD 2 cm HD 3 5 cm CBD 6 cm

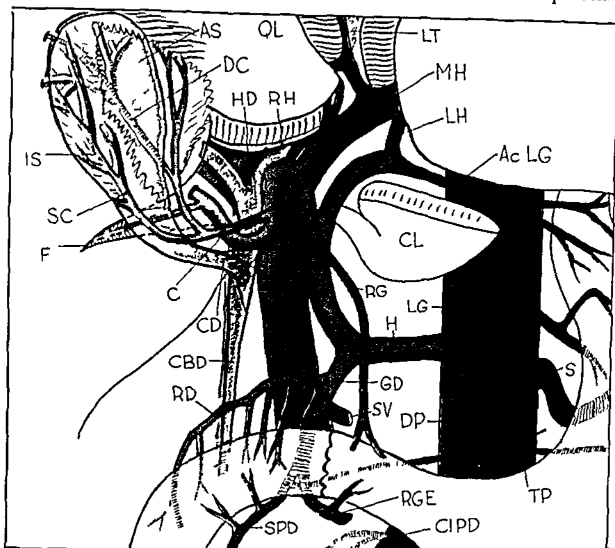


FIG 23 Typical upward and downward caterpillarlike loops made by the right hepatic (RH) as it crosses the hepatic duct (HD) anteriorly Single cystic (M N adult) The cystic artery (C) is in *a precarious position as it crosses the lower caterpillar like loop of the RH A search for it may have caused surgical harm to the common hepatic duct and to the main RH* A branch of the latter to the fissured area (F) could have been mistaken for the C especially as it courses somewhat parallel with and close to the cystic duct (CD) The branch most probably pertains to the posterior segment of the right lobe

The large accessory left gastric (AcLG) given *off by the LH represents an instance* in which the *upper part* of the primitive vascular arch between the LH and the left gastric (LG) persisted Such large accessory LG are relatively infrequent (3%) usually the lower part of the arc persists giving rise to an accessory (AcLH) or a replaced left hepatic (ReLH) the 2 types comprising 25%

The CD opens anteriorly and to the left In its spiral course it lies near the lower loop of the RH Attachment of the gall bladder (GB) was 2 cm wide 5 cm long *As is frequently the case the common* bile duct (CBD) tapers as it approaches the duodenum the retroduodenal part of the duct having a diameter less than one half the duct had at its beginning CD 3 cm HD 2 cm CBD 7 cm

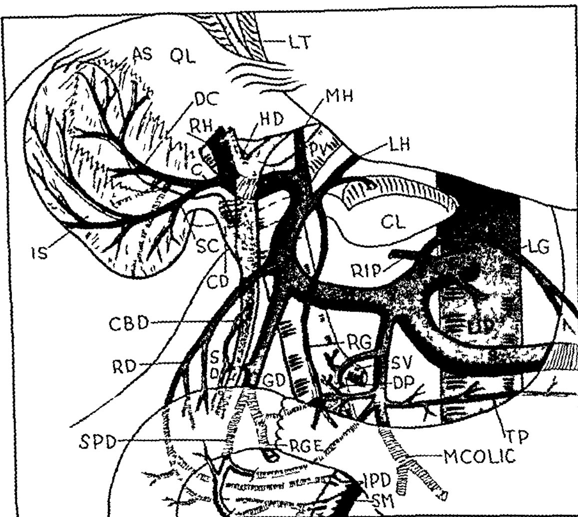


FIG 26 High leftward loop made by the right hepatic (RH) lodging that artery behind the bifurcation point of the hepatic duct (HD) Middle colic (MCol) from the celiac (CA) Single cystic (M W 73 yrs)

The cystic artery (C) has a short stem dividing nearly immediately into its superficial (SC) and deep (DC) branches the gemellae cysticae of Vesalius Both the cystic duct (CD) and the common HD readily may be injured in looking for the C *The MCol here takes origin from the CA The possibility of such origin should always be borne in mind when resecting in this region* Before passing under the splenic vein (SV) behind the pancreas the MCol gives off the dorsal pancreatic (DP) Proceeding downward to the inferior border of the pancreas it gives off the transverse pancreatic (TP) to the left and to the right sends 2 branches one of which joins the right gastro-epiploic (RGE) the other receiving the upper anterior pancreaticoduodenal arcade

The supraduodenal artery of Wilkie (SD) a branch of the gastroduodenal (GD) supplies the first inch of the duodenum and the supraduodenal and the retroduodenal parts of the common bile duct (CBD) The right gastric (RG) arises from the left hepatic (LH)

The CD opens posterolaterally and is tied to the HD Note the tapering of the CBD as it approaches the duodenum a common phenomenon CD 3 cm HD 3 cm CBD 7 cm

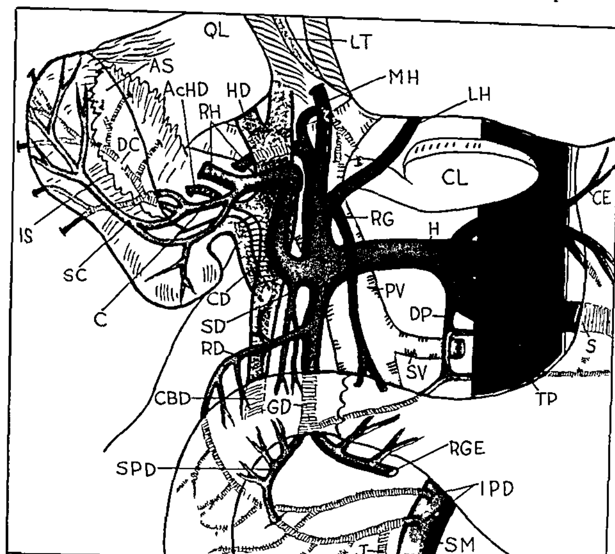


FIG 25 A case with *2 right hepatic arteries* (RH) the hepatic duct (HD) lying between them Single cystic (M W 77 yrs)

Surgical hazards here comprise (1) the presence of 2 RH one *anterior* the other *posterior* to the HD (2) a short parallel type of cystic duct (CD) it being tied to the HD for 2 5 cm and having its opening on the dorsal wall (3) an accessory hepatic duct (AcHD) is crossed by the cystic artery (C) and lies dangerously close to a RH and the CD (4) the greater part of the HD is overlain by the main right hepatic branch

Anterior and posterior pancreaticoduodenal arcades join the superior mesenteric (SM) via a separate inferior pancreaticoduodenal (IPD) that for the posterior arcade being higher than that for the anterior As the retroduodenal (RD) crosses the supraduodenal part of the common bile duct (CBD) it supplies the latter with twiglike branches *which may readily be injured or destroyed in explorations of the CBD with resultant necrosis* (Appleby) The CD is tied to the HD for 2 5 cm before opening posteriorly CD 4 cm HD 4 cm CBD 7 cm

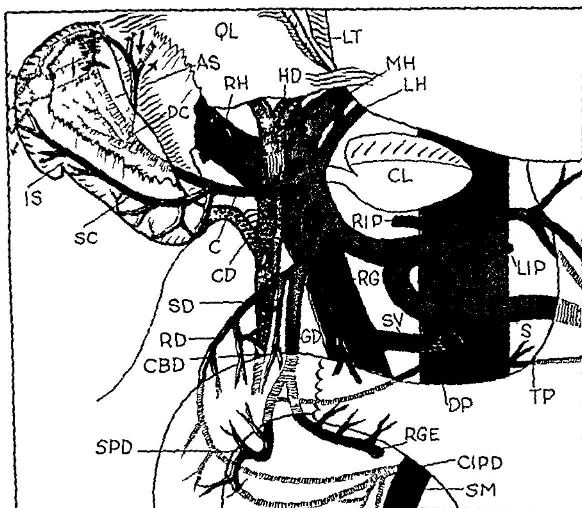


FIG 28 A large deep cystic artery (DC) after supplying the anterior surface of the gallbladder (GB) sinks into the GB bed to become a *liver artery* (M N 61 yrs)

The left gastric (LG) arises separately from the aorta (A) and gives rise to the left inferior phrenic (LIP) The hepatic (H) and the splenic (S) arise from a hepatolienal trunk which at its origin gives off the dorsal pancreatic (DP)

The cystic artery (C) was very large (2 mm) and very long (8 cm) It arose to the left of the hepatic duct (HD) from the H proper Severance of the blood supply to the GB here presents a technical difficulty to avoid extensive bleeding and possible ischemia of the liver parenchyma adjacent to the GB bed for the DC supplied relatively large liver twigs The supraduodenal part of the common bile duct (CBD) received twigs from the retroduodenal (RD) and the supraduodenal (SD) arteries

The cystic duct (CD) was tied to the lateral side of the HD for 1 5 cm before opening (short parallel type) Note the sudden tapering of the common bile duct (CBD) as it approaches the duodenum CD 3 cm HD 1 5 cm CBD 6 cm

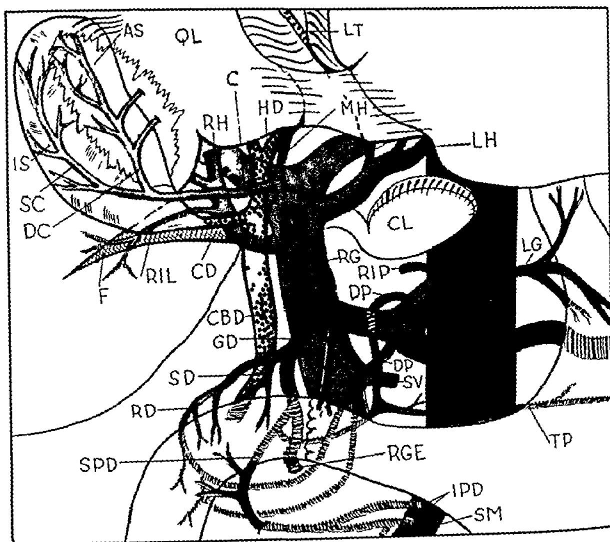


FIG 27 Upward and downward loop made by the right hepatic (RH) before entering the cystic triangle its course lodging it at the junction point of the cystic duct (CD) and the hepatic duct (HD) Single cystic (C) from the middle hepatic (MH) (M N 67 yrs)

Cystic artery (C) arises *outside Calot s triangle from the MH* crosses the HD anteriorly then courses parallel with and above a liver branch (RIL) of the RH that supplies the fissured area (F) The artery to the fissured area lies deep but if exposed by probing (RIL) may be mistaken for the C There are 2 dorsal pancreatic arteries (DP) The one from the celiac (CA) gives rise to the transverse pancreatic (TP) the other stemming from the hepatic (H) receives part of the retroduodenal (RD) arcade The supraduodenal (SD) sends a branch to the common bile duct (CBD) which becomes tapered as it approaches the duodenum CD 2 cm HD 2 5 cm CBD 8 cm

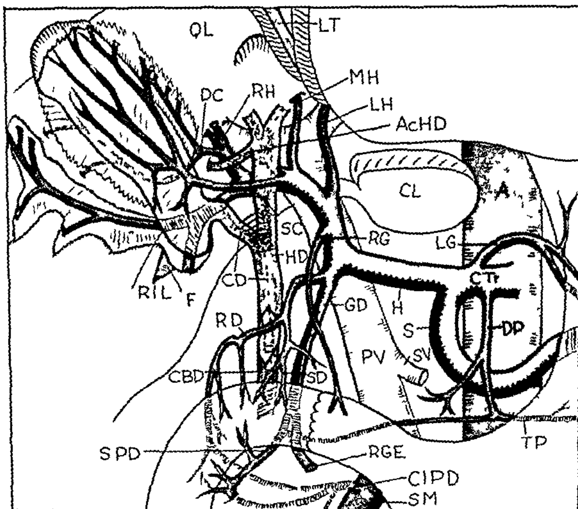


FIG 30 Double cystic artery As frequently is the case the deep cystic (DC) arises high in Calot s triangle the superficial (SC) outside it Accessory hepatic duct (AcHD) (M W 90 yrs)

The hidden and short cystic artery (C) is related to an AcHD that may be injured during surgical manipulation *The long SC after crossing the hepatic duct (HD) anteriorly is related to the lower branch of the right hepatic (RIL) probably the posterior segmental branch of the right lobe that enters the liver substance at the fissured area (F) under the gallbladder (GB)* Surgical hazards are apparent—in particular the danger of severing a main liver artery *(RIL) here partly dissected to show its area* of distribution

The cystic duct (CD) is very long (6 cm) runs parallel with and behind the HD to which it is tightly bound for 4 cm before opening thus making the supraduodenal part of the common bile duct (CBD) very short. Such long parallel ducts may *harbor residual gallstones* (now being detected roentgenographically at operation) and readily may be injured *in explorations of* the CBD The blood supply to the CBD from the supraduodenal artery of Wilkie (SD) should be noted to avoid devascularization of the duct and its possible subsequent necrosis (Appleby) CD 6 cm HD 7 cm CBD 1 cm

FIG 29 Origin of the cystic (C) from the celiac right hepatic (RH) to the left of the hepatic duct (HD) which it crosses anteriorly Anastomosis (ANAS) of the middle colic (MCol) with the hepatic (H) via the dorsal pancreatic (DP) (M N 71 yrs)

Frequently (20%) the C does not arise in Calot's triangle but takes origin from a RH a middle hepatic (MH) or a left hepatic (LH) to the left of the HD which it then crosses in most instances (18%) anteriorly The large artery descending from the RH in the cystic triangle is an oddly disposed liver branch (RIL probably the posterior segmental branch) entering the fissured area (F) under the gallbladder (GB)

The retroduodenal (RD) is a branch of the DP and not of the gastroduodenal (GD) thereby justifying its specific nomenclature It and the supraduodenal (SD) supply the common bile duct (CBD) the one anteriorly the other posteriorly The DP after giving off the transverse pancreatic (TP) does not end at the posterior inferior border of the pancreas but continues downward to communicate with the MCol thereby establishing an anastomosis between the superior mesenteric (SM) and the H Such anastomoses occur frequently and afford a collateral pathway to the liver via the SM In old texts of anatomy this ramus connecting the celiac (CA) with the SM was known as the *ramus anastomoticus* of Buhler

Note 2 common features of the CBD (1) its ampullation at the junction point of the cystic duct (CD) and the HD (2) its progressive tapering as it approaches the duodenum and passes under it CD 2 cm HD 3 cm CBD 8 cm

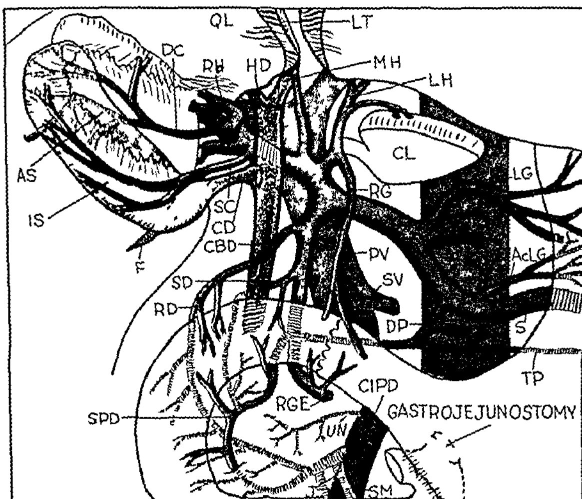


FIG 32 Dual cystic arteries both arising from the celiac right hepatic (RH) in the cystic triangle Accessory left gastric (AcLG) from the splenic (S) A gastrojejunostomy had been performed (M W 49 yrs)

The lower branch of the RH probably the posterior segmental branch lies *between the superficial (SC) and the deep cystic (DC)* and may be injured readily in a search for the cystic (C) A common inferior pancreaticoduodenal (IPD) receives the anterior and the posterior pancreaticoduodenal arcades The supraduodenal (SD) after supplying the first part of the duodenum and the common bile duct (CBD) passes behind the duodenum to anastomose with the superior pancreaticoduodenal (SPD) thereby proving it *not to be an end artery* as claimed by Wilkie The uncinate process of the pancreas receives a separate branch (Un) from the superior mesenteric (SM) Note the *jejunal branches from the common IPD to the critical first part of the jejunum* Often an AcLG from the S ascends behind the stomach as here It is the ramus esophagogastricus posterior ascendens not mentioned in textbooks In many instances the transverse pancreatic (TP) takes origin from the gastroduodenal (GD) as here the vessel in its course anastomosing with the dorsal pancreatic (DP) from the S CD 2 5 cm HD 3 cm CBD 7 cm

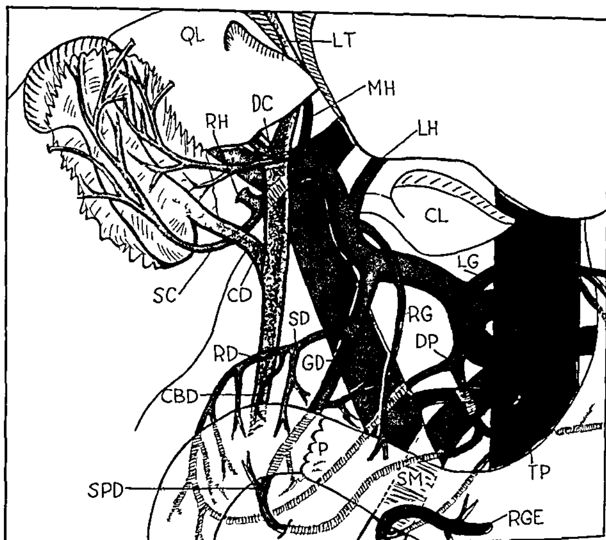


FIG 31 Double cystic artery the reverse of Figure 30 for here the deep cystic (DC) arises *outside* Calot s triangle whereas the superficial (SC) takes origin *inside* it The right gastro epiploic (RGE) has a separate origin from the superior mesenteric (SM) as frequently is the case (M N adult)

The DC arises from the middle hepatic (MH) showing that *branches other than the right hepatic (RH) may give rise to a cystic (C)* The precarious course of the SC should be noted After taking origin from the RH in the triangle it *swerves around* i e *below the cystic duct (CD)* to become distributed to the peritoneal surface of the gallbladder (GB) where it can be seen

The wide (4 mm) dorsal pancreatic (DP) from the first part of the splenic (S) passes behind the SM One upper branch coursing dorsal to the portal vein (PV) picks up the retroduodenal arcade and a lower branch receives the anterior pancreaticoduodenal arcade Distally it gives off the transverse pancreatic (TP) to the left and a branch which unites with the RGE which here has a separate origin from the SM CD 2 5 cm HD 3 cm CBD 5 cm

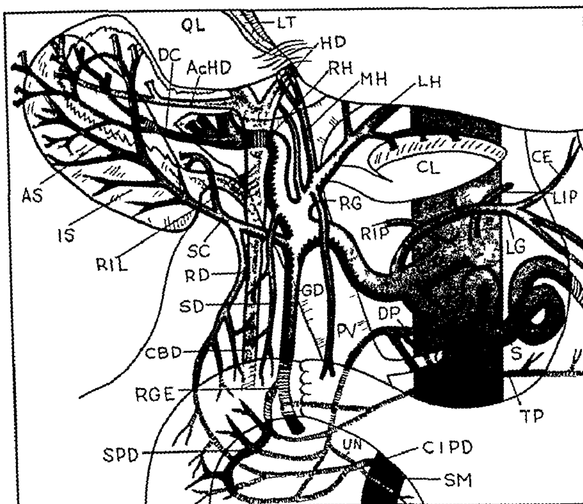


FIG 31 Origin of the superficial cystic artery (SC) *from an intestinal artery* viz the retroduodenal (RD) Deep cystic (DC) from right hepatic (RH) A subvesicular accessory hepatic duct (AcHD) complicates surgical hazards Tortuous splenic (M W 83 yrs)

The entire cystic (C) (2 cases) or its superficial branch (6 cases) may arise from the gastroduodenal (GD) via its RD branch Here it is quite arbitrary to state whether the RD arises from the SC or vice versa the SC from the RD Before reaching the peritoneal surface of the gallbladder (GB) the SC gives off a liver branch (KIL) The course of the SC should be noted for *ordinarily the surgeon does not look for a C caudal to the cystic duct (CD)* The DC lies high in Calot's triangle and springs from a branch of the RH

Quite frequently an AcHD courses in the GB bed where it readily may be mistaken for a nerve or a connective tissue fiber and thus be torn in cholecystectomy with resultant postoperative leakage of bile Here the subvesicular AcHD (7 cm long) ran in a groove adjacent to the quadrate lobe (QL) then rose to the surface to reach the GB bed where it was clearly visible the plane of its course being dorsal to that of the DC The supraduodenal (SD) arises high from the RH and along with the RD supplies the common bile duct (CBD) The splenic (S) is markedly tortuous being thrown into numerous loops and coils as is often the case in aged individuals (here 83 yrs) The dorsal pancreatic (DP) communicates to the right with the right gastroepiploic (RGE) the superior pancreaticoduodenal (SPD) the RD and supplies the uncinate process (Un) of the pancreas with a branch CD 2 cm HD 3 cm CBD 9 cm

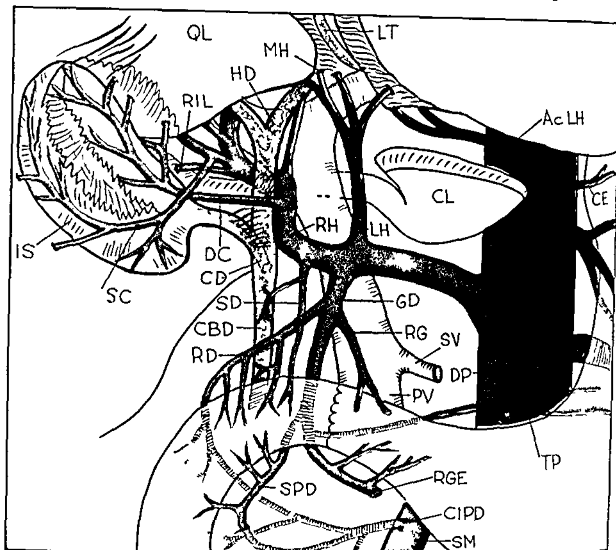


FIG 33 Crisscrossing of the superficial (SC) and the deep (DC) cystic arteries the former arising *outside* Calot s triangle the latter *inside* it An accessory left hepatic (AcLH) from the left gastric (LG) (M W adult)

The right hepatic (RH) is precariously close to the hepatic duct (HD) The DC after crossing the HD anteriorly coursed along the left side of the peritoneal surface of the gallbladder (GB) while the SC from an end branch of RH coursed on the right side—an odd pattern of both cystics (C) having a distribution on the peritoneal surface and *crisscrossing* Seen but once The supraduodenal (SD) is a branch of the hepatic (H) In its descent to the first inch of the duodenum it gave off a branch to the common bile duct (CBD) a comparable branch coming from retroduodenal (RD)

Attachment of the GB was 3 cm wide 4 cm long The short parallel cystic duct (CD) was tied to the HD for 1 cm and opened posteriorly CD 3 cm HD 4 cm CBD 4 cm

FIG 36 Odd origin of the *middle colic* (MCol) from a replaced right hepatic (ReRH) derived from the superior mesenteric (SM) the artery passing behind the superior mesenteric vein (SMV) and giving off the dorsal pancreatic (DP) and its transverse pancreatic (TP) branch (M W 66 yrs)

The celiac hepatic distally supplies only the left hepatic (LH) and the middle hepatic (MH) thereby making the celiac artery (CA) an *incomplete* hepatolienogastric trunk A hepatomesenteric trunk gives off the ReRH to which was shifted *the site of origin of the MCol and the site of anastomosis of the anterior and the posterior pancreaticoduodenal arcades via 2 separate inferior pancreaticoduodenals* (IPD) The DP instead of arising from the SM here takes origin from the MCol Reaching the inferior surface of the pancreas it gives off its characteristic left branch the TP which courses to the tail of the pancreas

The first branch of the ReRH in Calot's triangle is not the cystic artery (C) but a liver branch (RIL probably the posterior segmental branch of Healey and Schroy) that enters the fissured area (F) *When exposed by deep probing it may be mistaken for the C which lies above it* The case warrants the admonition that *an artery which looks like the C and which runs close to or parallel with the cystic duct (CD) is not necessarily the C (Cole)*

The common bile duct (CBD) receives a blood supply from the supraduodenal (SD) anteriorly and from the retroduodenal (RD) posteriorly The gallbladder (GB) was 8 cm long Distally the CBD tapered at its *beginning it was* ampullated CD 3 cm HD 3 cm CBD 6 cm

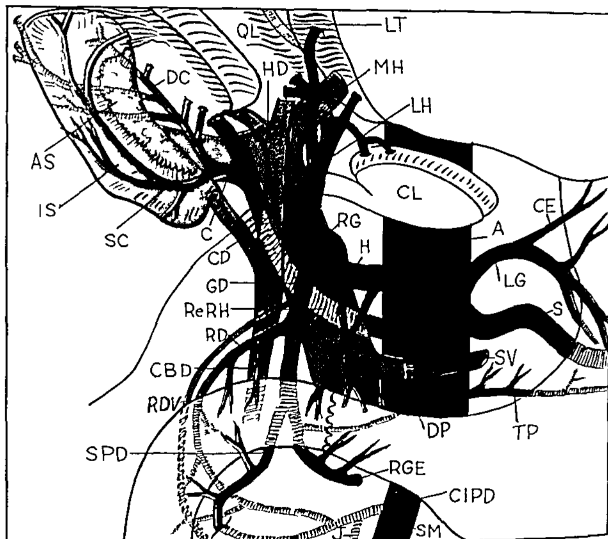


FIG 35 Aberrant origin of the right hepatic (ReRH) from the celiac artery (CA) the distal end of which divides into the left hepatic (LH) and the gastroduodenal (GD) (M N 67 yrs)

When the right hepatic (ReRH) has an *independent* origin from the CA as is frequently the case in most instances it courses *dorsal* to the portal vein (PV) to reach the cystic triangle where it may lie ventral to the right branch of the PV as here Note the close relation of the ascending ReRH to the junction point of the cystic duct (CD) and the hepatic duct (HD) the CD being tied to the HD for a stretch of 1 5 cm In trying to free the CD the main ReRH and the common bile duct (CBD) may be injured accounting for the relatively frequent injuries to the CBD in this region (Lahey Walters)

The stem of the cystic artery (C) is very short *as the artery nearly immediately divides into its superficial (SC) and deep branches (DC)* the gemellae cysticae of Vesalius Dorsal pancreatic (DP) from the CA as is frequently the case (22%) It readily may be found at the junction point of the splenic vein (SV) with the superior mesenteric vein (SMV) Its characteristic left branch is the transverse pancreatic (TP) which anastomoses at the tail of the pancreas with the splenic terminals

Note the retroduodenal vein (RDV) as it joins the PV behind the CBD It drains the retroduodenal venous arcade which lies dorsal to the arterial retroduodenal arcade on the back of the duodenum and the head of the pancreas the thin fascia (original mesoduodenum) of Treitz covering both arcades

As is commonly the case the common duct is ampullated at its beginning and tapered at its distal end CD 3 cm HD 5 cm CBD 5 cm

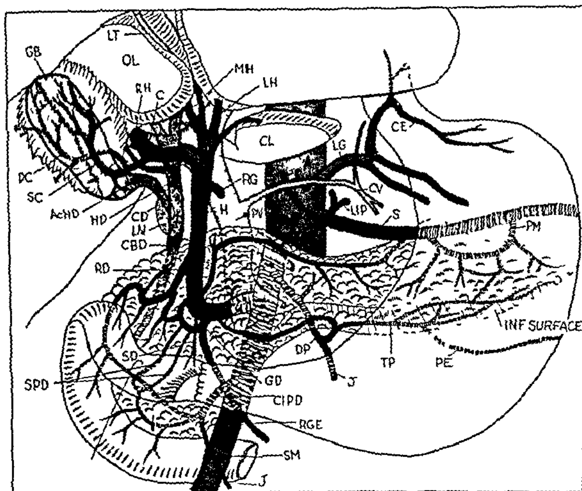


FIG 88 The common hepatic artery (H) passes *through the head of the pancreas* after taking origin from the superior mesenteric (SM) Hepatomesenteric trunk The left gastric (LG) and the splenic (S) arise from a henogastric trunk Single cystic (M N 16 yrs)

The entire arterial blood supply to the liver came *from a replaced common hepatic* which arose from the SM 1 cm distal to its commencement *It passed abruptly through the head of the pancreas* and was 6 cm long between its division into 3 hepatic branches and the site of origin of the right gastro-epiploic (RGE) As it coursed over the anterior surface of the pancreas it simulated the position of the gastroduodenal (GD) and on first inspection was mistaken for that artery Further dissection showed *that the GD was very short and* that it resolved itself into a RGE 2 superior pancreaticoduodenals (SPD) and 2 branches which coursed to the left one uniting with the S the other with the dorsal pancreatic (DP) Severance of *the depicted H during a pancreaticoduodenal resection would have resulted in immediate death of the patient*

The cystic triangle presents a common surgical hazard The short cystic (C) crosses an accessory hepatic duct (AcHD) which runs parallel with the cystic duct (CD) Note the lymph node of Luschka or gan*glion of Terrier that often obstructs visualization* and identification of structures

The double *anterior (2 SPD) and the* single posterior pancreaticoduodenal arcades end in a common inferior pancreaticoduodenal (IPD) As is frequently the case the transverse pancreatic (TP) takes origin from a DP derived from the SM Coursing along the inferior surface of the pancreas it gave off a posterior epiploic (PE) branch *to the* transverse mesocolon (*TrCol*) and anastomosed with branches (PM) of the S To the right the TP gave *a branch which* passed *from the* dorsal to the ventral surface where it united with a branch of the SPD CD 3 *cm* HD 3 5 cm CPD 6 cm

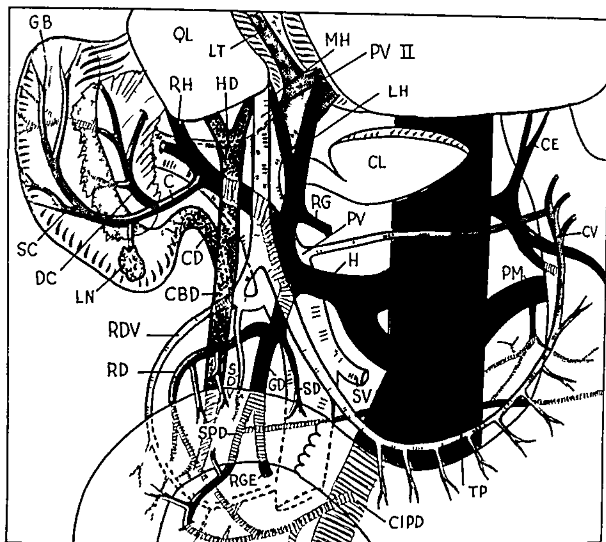


FIG 37 Double portal vein the second portal vein (PV II) being anterior to the right hepatic artery (RH) and formed by the confluence of a branch of the retroduodenal vein (RDV) and a vein draining the lesser curvature seen but once in 500 bodies (I W 38 yrs)

The coronary vein was small and drained into the main PV Coursing anterior to the left gastric (LC) it communicated with a vein which as it followed the lesser curvature became larger and ultimately united with a branch of the RDV as the latter joined the PV behind the common bile duct (CBD) The RDV received a tributary from the first part of the duodenum via the supraduodenal vein

When the duodenum is mobilized and its back is exposed 2 pancreaticoduodenal arcades are visible through the thin fascia of Treitz (original mesoduodenum) covering them The superficial arcade is venous and is made by the RDV which is a tributary to the PV The deep arcade is arterial and is made by the retroduodenal artery (RD) which after its origin from the gastroduodenal (GD) descends to spiral around the CBD at first anteriorly then posteriorly thus placing the distal part of the CBD in an arterial ring Interference with the blood supply here may lead to *necrosis of the CBD* (personal communication Appleby of Canada 1953) In closure of a duodenal stump a *life sustaining blood supply* of it should always be inspected lest the stump be left to blow out with *fatal results* suture lines not holding and breaking because an adequate blood supply was not provided

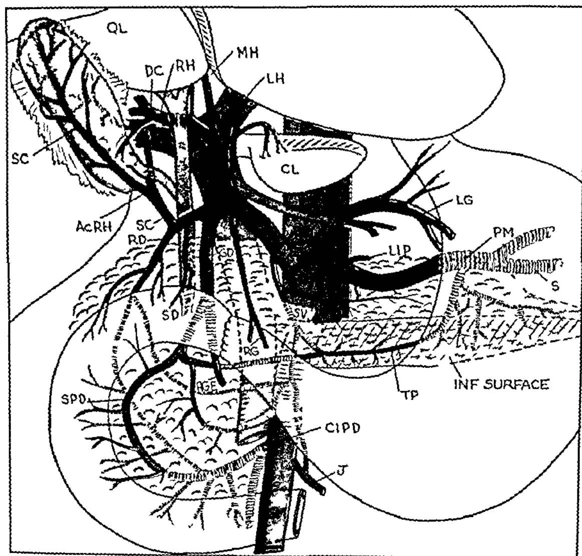

QL
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RH
LH
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CL
LG
AcRH
SC
RD
PM
GD
LIP
S
SD
SV
RG
INF SURFACE
TP
RGE
SPD
CIPD
J

FIGURE 39

FIG 39 Origin of the superficial cystic artery (SC) from the gastroduodenal (GD) via its retroduodenal (RD) intestinal branch (6 cases) Double anterior and double posterior pancreaticoduodenal arcades Dual cystics (M W 62 yrs)

The RD after crossing the common bile duct (CBD) anteriorly gives off an ascending branch which at the lower border of the cystic duct (CD) divides into the SC *and a liver branch (3 mm) which functions as an accessory right hepatic* (AcRH) The deep cystic (DC) arises high in the triangle

There are 2 anterior and 2 posterior pancreaticoduodenal arcades The outer posterior and the outer anterior arcades unite with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) The inner posterior and the inner anterior arcades unite with a branch of the dorsal pancreatic (DP) that ultimately joins a jejunal branch

The DP arises from the first part of the common hepatic (H) supplying the neck region of the pancreas dorsally it descends behind the splenic vein (SV) at the latter s junction with the superior mesenteric vein (SMV) Reaching the inferior surface of the pancreas it gives off a left branch that communicates with the transverse pancreatic (TP) and a descending branch that receives the upper anterior and the posterior pancreaticoduodenal arcades (via a branch which passes behind the SMV but anterior to the SM) and ultimately unites with the SM via a jejunal branch

The TP 10 cm long springs from the superior pancreaticoduodenal (SPD) and passes anterior to the SMV to reach the inferior surface of the pancreas along which it courses to unite with the arteria pancreatica magna (PM) of the splenic (S)

Multiple collateral pathways may be established by the TP It is anastomosed to the H via the DP to the S via the PM to the RD via a right branch to the SPD from which it springs and to the SM via a jejunal branch

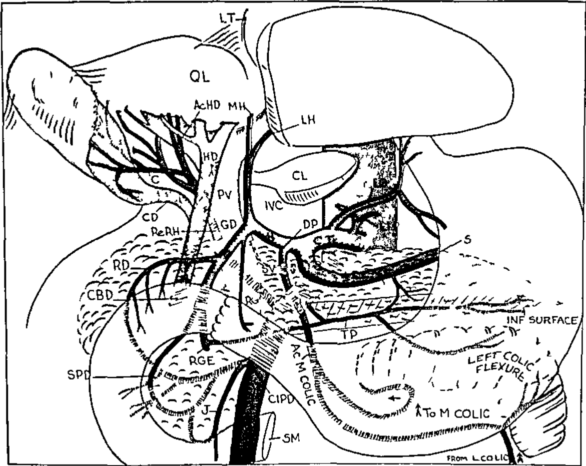


FIG 11 An accessory middle colic (AcMCol) supplying the distal third of the transverse colon and arising from the hepatic (H) via the dorsal pancreatic (DP). Incomplete hepatolienogastric trunk. Single cystic. Accessory hepatic duct (M W adult.)

The distal third of the transverse mesocolon (TrCol) the so called avascular area of Riolan may have coursing through it an *AcMCol which arises from an artery in the supramesocolonic region*. Here it takes origin from the first part of the H via the DP. The latter after passing behind the splenic vein (SV) descends to the inferior surface of the pancreas here it gives off its characteristic left transverse pancreatic branch (TP) then continues downward as a mesenteric artery (AcMCol) which bifurcates the upper branch uniting with the left branch of the MCol the lower branch with the ascending branch of the left colic (LCol). An additional artery to the LCol flexure is supplied by the TP.

The blood supply to the right lobe of the liver comes from a replaced right hepatic (ReRH) which after its origin from the superior mesenteric (SM) passes behind the portal vein (PV) to reach the cystic triangle. Reaching the latter it gives off a liver branch and a long cystic (C) the latter crossing the former.

High in the cystic triangle is an accessory hepatic duct (AcHD) passing anterior to one of the branches of the ReRH. It is sufficiently high to be out of surgical harm. The cystic duct (CD) passes behind the hepatic duct (HD) to become united with it for some distance before opening into the 4 cm long common bile duct (CBD). Note the relations of the retroduodenal artery (RD) which may be injured readily during exploration of the CBD with resultant disconcerting hemorrhage (Appleby of Vancouver B C Canada)

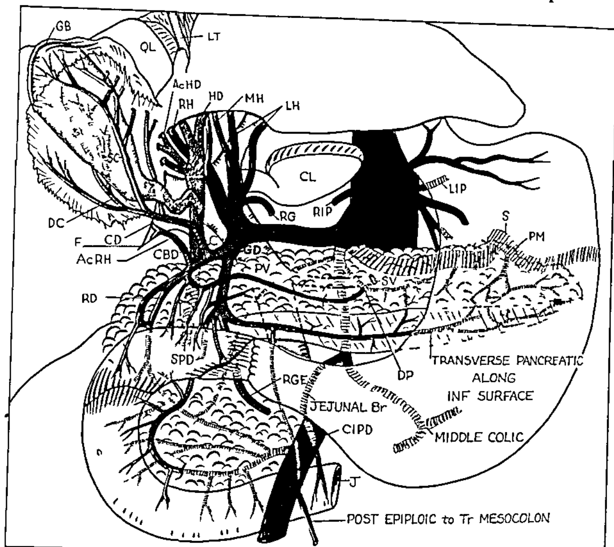


FIG 10 A typical origin of the cystic artery (C) and of the *middle colic* (MCol), the former from the retroduodenal (RD), an intestinal artery, the latter from the celiac trunk (CTr). High accessory hepatic duct (M W 72 yrs)

Here not only the superficial branch of the cystic (SC) (6 cases) but also the *entire C* (2 cases) comes from the gastroduodenal (GD) via its RD branch, which in addition gives a small branch (AcRH) to the fissured area (F) under the gallbladder (GB). Before dividing into its superficial (SC) and deep (DC) branches the C sends a twig to the liver.

The cystic duct (CD) is short (2 5 cm), spirals and opens anteriorly and to the left of the hepatic duct (HD). The shortness of the HD (2 5 cm), the fact that it receives an accessory hepatic duct (AcHD) and overlies 2 main branches of the right hepatic (RH) makes a surgical manipulation of the structures in and about the cystic triangle a *hazardous procedure*.

Inexcusable is a noncognizance of the fact that the middle colic (MCol) may take origin from the celiac trunk instead of the superior mesenteric (SM) and that in such instances it emerges from the dorsal border (inferior surface) of the pancreas as shown here. An *accessory middle colic (AcMCol)* may have the same celiac origin, being distributed to the distal *third of the transverse colon and the left colic flexure as the artery of Riolan*. Before passing behind the splenic vein (SV) the MCol gives off the dorsal pancreatic (DP) and at the inferior border of the pancreas it *gives off a large branch to the duodenojejunal flexure, a critically vascularized area*, as all surgeons know.

The transverse pancreatic (TP) takes origin from the GD after giving off a posterior epiploic (PE) branch to the transverse mesocolon (TrCol); it courses along the inferior surface of the pancreas for 9 cm. United distally with the splenic (S) via the PM, it constitutes a long transpancreatic collateral pathway between the spleen and the liver.

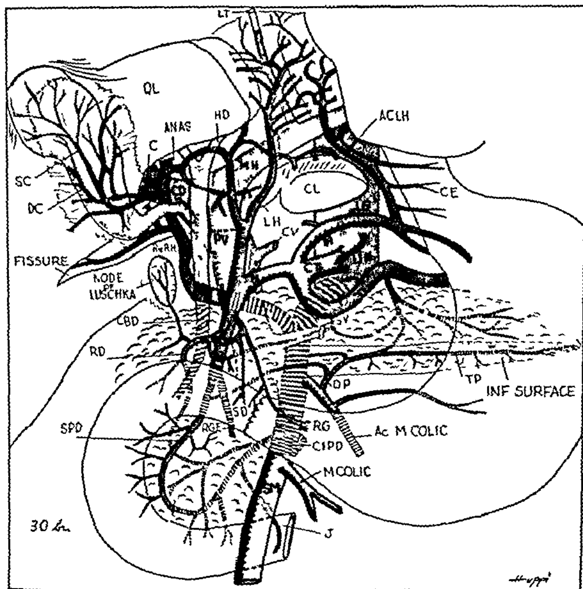

LT
QL
ANAS
HD
ACLH
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SC
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CBD
RD
SV
TP
OP
INF SURFACE
SD
SPD
RGE
RG
Ac M COLIC
CIPD
M COLIC
30 hr.
J

FIGURE 42

Fig 12 An accessory middle colic (AcMCol) from the superior mesenteric (SM) to the distal third of the transverse colon Tripod type of incomplete celiac hepatolienogastric trunk Single cystic (F N 52 yrs)

The dorsal pancreatic (DP) usually a branch of the first part of the hepatic (H) *or the splenic (S) here arises from an AcMCol* which affords the transverse colon with an additive blood supply in its distal third (splenic flexure) As typically the case when of such origin the DP gives off the transverse pancreatic (TP) that courses along the inferior surface of the pancreas and anastomoses with the S via its a pancreatica magna (PM) branch

The right hepatic (ReRH) replaced from the SM in its ascent to the liver passes behind the portal vein (PV) becomes folded about the long common bile duct (CBD) (10 cm) is partly hidden by the lymph node of Luschka (LN) (ganglion of Terrier) and before entering the cystic triangle gives off a large branch (RIL) to a fissured area (5 cm long) beneath the gallbladder (GB) This fissure branch if exposed by unnecessary deep dissection readily *may be mistaken for the cystic (C)*, which here lies above the short cystic duct (CD) Note the anastomosis (ANAS) between the left hepatic (LH) and the accessory left hepatic (AcLH) in the umbilical fossa and the node of Luschka (LN) or the ganglion of Terrier about the CBD

The anterior and the posterior pancreaticoduodenal arcades made respectively by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) end in a common inferior pancreaticoduodenal (IPD) which here springs from the left side of the SM The RD winds around the CBD first anteriorly above the duodenum then posteriorly in back of the pancreas placing it in an arterial circle The right gastric (RG) from the gastroduodenal (GD) forms an arcade with the RD the arcade giving off the supraduodenal (SD) A branch of the middle hepatic (MH) supplies the caudate lobe proper (CL) The caudate process is supplied by a branch of the ReRH that passes dorsal to the PV and the hepatic duct (HD) and is anastomosed with the MH CD 2 cm HD 2 cm CBD 10 cm

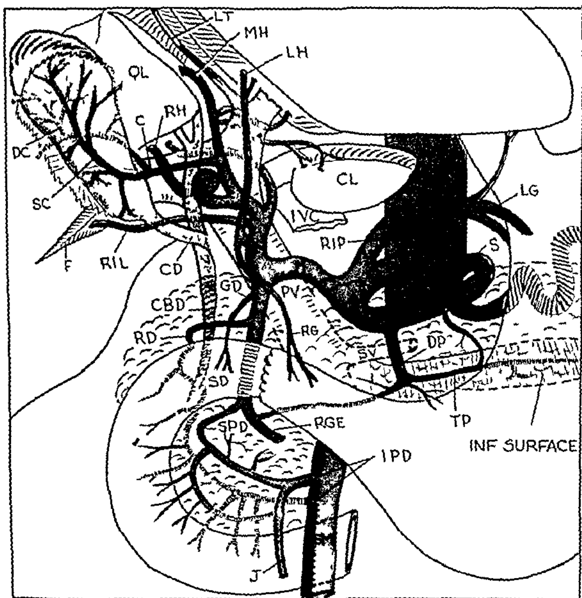


FIG 44 A precariously situated coil made by the right hepatic (RH) before crossing the hepatic duct (HD) Single cystic (C) from the middle hepatic (MH) crossing the HD Coiled and tortuous splenic (S) (M W 66 yrs)

The C does not arise in the cystic triangle but takes origin *outside it from the MH* It crosses the HD anteriorly above the RH which here had made a full spiral before passing under the HD Below the spiral a branch of the right hepatic (RH) courses to a fissured area (F) under the gallbladder (GB) In the cystic triangle it lies close to the cystic duct (CD) and may readily be *mistaken* for the C Most probably it represents the posterior segmental artery of the right lobe

The CD crosses the HD anteriorly and has its opening on the left side anteriorly The right gastric (RG) and the left hepatic (LH) arise in a common trunk from the hepatic proper artery (H) after the gastroduodenal (GD 6 cm long) has been given off from the H The MH sends a large branch to the left lobe and supplies the caudate lobe (CL) The 2 anterior pancreaticoduodenal arcades end in the superior mesenteric (SM) via a separate inferior pancreaticoduodenal (IPD) which sends off a jejunal branch to the critical first part of the jejunum

The retroduodenal artery (RD) spirals about the common bile duct (CBD) its arcade uniting with the SM via a separate IPD

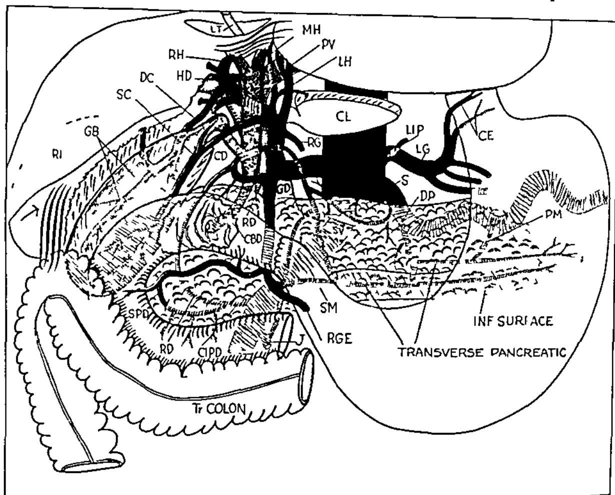


FIG 43 A hidden gallbladder (GB) a large part of it behind the duodenum Hepatolienogastric celiac trunk Double cystic artery (C) (M W 52 yrs)

The GB measuring 8 cm by 3 5 cm was attached to its bed by a short (1 cm) mesentery A large part of it was *hidden behind the descending duodenum* its tip being covered by the transverse colon A cystocolic ligament formed a roof over the region making the case appear as a *congenital absence of the GB* when the abdomen was opened Except for its mesenteric attachment the entire anterior surface of the GB was free and covered by peritoneum It could be reached by pushing a finger under the cystocolic ligament No attachment to the kidney was noted

The dual cystics arose from the right hepatic (RH) at different sites The deep cystic (DC) took origin high in the cystic triangle and descended to the anterior surface of the GB the superficial cystic (SC) arose from the RH to the left of the hepatic duct (HD) and became distributed to its inferior surface

The dorsal pancreatic (DP) was anastomosed with two transverse pancreatic arteries (TP) the upper TP routed its way near the anterior surface of the pancreas and became united with the splenic (S) via its large pancreatic branch (PM) the lower TP sprang from the right gastro-epiploic (RGE) and coursed along the inferior surface of the pancreas The retroduodenal (RD) gave off a branch that swung *behind* the common bile duct (CBD) and the hepatic artery (H) and communicated with the S the lower TP and the superior mesenteric (SM) for the latter via a *jejunal branch*

Note the difference between the caliber of the HD and that of the CBD the latter tapering considerably as it passes through the pancreas and the duodenum

FIG 46 Very odd retropancreatic origin of the gastroduodenal (GD) from the superior mesenteric (SM) the artery furnishing the superficial cystic (SC) in its course behind the common bile duct (CBD) Dual cystics (C) (F W adult)

Surgically considered 2 important anatomic anomalies should always be remembered from this case to wit *that the GD may arise from the SM and that the SC may course caudad to the cystic duct (CD) after its origin from an intestinal artery*

The usual GD given off by the hepatic (H) was about half the normal size and was anastomosed with the major GD derived from the SM In its course behind the head of the pancreas the large GD gave off the SC swung around the lateral side of the CBD to reach the ventral surface of the pancreas where it divided into its typical end branches (SPD RGE) The deep cystic artery (DC) arose in the cystic triangle from the right hepatic (RH) the SC arose outside the triangle from the GD coursed behind the CBD and ascended to the free peritoneal surface of the gallbladder (GB) caudad to the CD which it crossed anteriorly The retroduodenal (RD) arose as a collateral of the GD *thereby justifying its specific name* The posterior pancreaticoduodenal arcade made by it was picked up by a posterior branch of the anterior pancreaticoduodenal arcade and both joined a common inferior pancreaticoduodenal (IPD) derived from the dorsal pancreatic (DP) to the left of the SM

As is commonly the case (14%) the DP arose from the SM and upon reaching the inferior surface of the pancreas divided into 2 main branches viz one left branch that became the transverse pancreatic (TP) and anastomosed with the a pancreatica magna (PM) of the splenic (S) and a right branch that joined the GD supplying the supraduodenal (SD) before doing so A large recurrent branch of the left inferior phrenic (LIP) gave off cardioesophageal (CE) branches that anastomosed *with similar* branches from the left gastric (LG) CD 3 cm HD 2 cm CBD 6 cm

FIG 45 Specimen illustrating the abundant blood supply to the biliary tract effected by ascending and descending branches of the retroduodenal (RD) by twigs from the supraduodenal (SD) and the right hepatic (RH) Large accessory left gastric (AcLG) from the splenic (S) Single cystic (C) (F W 77 yrs)

The supraduodenal part of the common bile duct (CBD) is crossed anteriorly by the RD After supplying a few branches to the first part of the duodenum the RD swerves behind the CBD on the head of the pancreas where it forms the posterior pancreaticoduodenal arcade The latter supplies branches to all 3 parts of the duodenum to the intrapancreatic part of the CBD including the ampulla of Vater The hepatic duct (HD) here is supplied by a branch of the RD which ascended along its posterior aspect and anastomosed with a branch of the RH As is commonly the case a branch of the RH supplied the cystic duct (CD) the pouch of Hartmann (fossa prevesicalis) and the regional lymph node of Luschka or ganglion of Terrier

The stem of the cystic (C) was very short as it sprang from a curved section of the RH The gastroduodenal (GD) (4 cm long) took origin from the middle of the hepatic (H) (4 cm long) and distally gave off 2 superior pancreaticoduodenals (SPD) The upper anterior pancreaticoduodenal arcade united with a branch of the dorsal pancreatic (DP) The lower anterior arcade picked up the posterior arcade and *both joined the superior mesenteric (SM) via a jejunal branch* As is commonly the case (14%) the DP arose from the SM To the left it gave off 2 transverse pancreatic branches (TP) The upper one was small and coursed near the ventral surface of the pancreas the lower one was large (3 mm) and as it coursed along the inferior surface of the pancreas it gave off posteriorly epiploic (PE) branches to the transverse mesocolon (TrCol) The entire caudate lobe was supplied by a branch of the left hepatic (LH) The AcLG from the S was distributed to the cardioesophageal and the fundic region of the stomach and accordingly is aptly termed the ramus esophagogastricus posterior ascendens

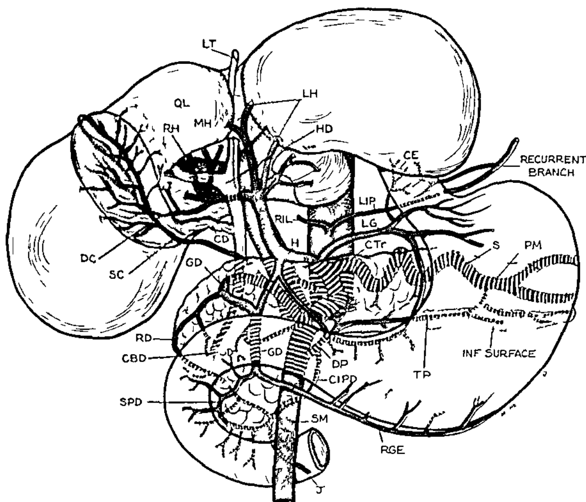


Fig 46 Very odd retropancreatic origin of the gastroduodenal (GD) from the superior mesenteric (SM) the artery furnishing the superficial cystic (SC) in its course behind the common bile duct (CBD) Dual cystics (C) (F W adult)

Surgically considered 2 important anatomic anomalies should always be remembered from this case to wit *that the GD may arise from the SM and that the SC may course caudad to the cystic duct (CD) after its origin from an intestinal artery*

The usual GD given off by the hepatic (H) was about half the normal size and was anastomosed with the major CD derived from the SM In its course behind the head of the pancreas the large CD gave off the SC swung around the lateral side of the CBD to reach the ventral surface of the pancreas where it divided into its typical end branches (SPD RGE) The deep cystic artery (DC) arose in the cystic triangle from the right hepatic (RH) the SC arose outside the triangle from the GD coursed behind the CBD and ascended to the free peritoneal surface of the gallbladder (GB) caudad to the CD which it crossed anteriorly The retroduodenal (RD) arose as a collateral of the GD *thereby justifying its specific name* The posterior pancreaticoduodenal arcade made by it was picked up by a posterior branch of the anterior pancreaticoduodenal arcade and both joined a common inferior pancreaticoduodenal (IPD) derived from the dorsal pancreatic (DP) to the left of the SM

As is commonly the case (11%) the DP arose from the SM and upon reaching the inferior surface of the pancreas divided into 2 main branches viz one left branch that became the transverse pancreatic (TP) and anastomosed with the a pancreatica magna (PM) of the splenic (S) and a right branch that joined the GD supplying the supraduodenal (SD) before doing so A large recurrent branch of the left inferior phrenic (LIP) gave off cardioesophageal (CE) branches that anastomosed with similar branches from the left gastric (LG) CD 3 cm HD 2 cm CBD 6 cm

FIG. 47. Origin of the superficial cystic artery (SC) behind the head of the pancreas from the superior mesenteric (SM) via the retroduodenal arcade. Dual cystics. (M. N. adult.)

The duodenum has been turned forward to show the primary and the secondary arcades made by the retroduodenal artery (RD) on the back of the head of the pancreas. The wider primary arcade gave off the SC. At first sight it seemed as though the SC (8 cm. long) *came directly from the SM*. Such origin occasionally has been reported in the literature (Below, 1 case) but in this study of 200 bodies it was never encountered, this case being the closest approach to such origin. A painstaking dissection of arterial connections showed that in this case the SC arose from *the RD arcade* that ended in the SM via its own inferior pancreaticoduodenal (IPD). A branch of the latter picked up a secondary posterior pancreaticoduodenal arcade. The anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) joined the SM at the level of origin of the middle colic (MCol) via its own IPD.

The gastroduodenal (GD), after a course of 4 cm., divided into 3 branches, the extra branch being the transverse pancreatic (TP) which, along its course on the inferior surface of the pancreas, gave off tiny slender posterior epiploic (omental) branches (PE) to the transverse mesocolon (TrCol), affording that structure with an additive blood supply. Distally in the tail of the pancreas it anastomosed with the arteria pancreatica magna (PM) of the splenic (S). The right hepatic (RH) was replaced from the SM, its total length being 10 cm. *In pancreaticoduodenal resections mobilization of the duodenum will reveal whether the SM gives off a hepatic artery (H) and whether one or two IPD are present.* The inferior phrenics (P) arose from the aorta (A) via a common stem. As is predominantly the case, the recurrent branch of the left inferior phrenic (LIP) gave off cardioesophageal (CE) branches that communicated with similar branches from the left gastric (LG). The caudate process was supplied by a branch of the RH, the caudate lobe proper (CL) by a branch of the left hepatic (LH).

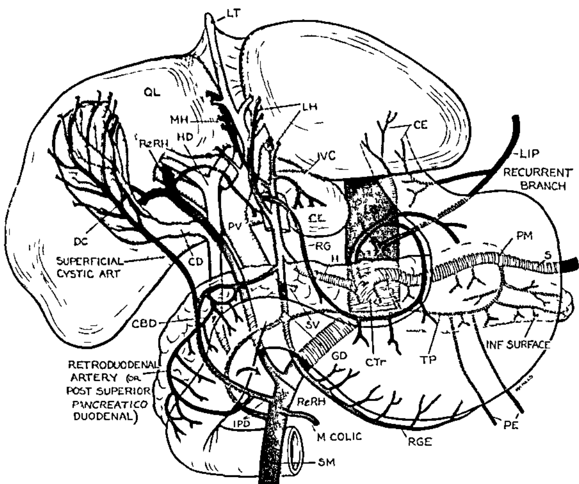

LT
QL
LH
MH
CE
RtRH
HD
IVC
LIP
RECURRENT BRANCH
PV
CE
DC
RG
PM
S
SUPERFICIAL CYSTIC ART
CD
H
CBD
SV
INF SURFACE
GD
CTr
TP
RETRODUODENAL ARTERY (OR POST SUPERIOR PANCREATICO DUODENAL)
ReRH
IPD
M COLIC
PE
RGE
SM

FIGURE 17

FIG 48 The common hepatic (H) divides into the right hepatic (RH) and the gastroduodenal (GD) leaving the left hepatic (LH) and the middle hepatic (MH) to arise i e be replaced from the left gastric (LG) Two large accessory left gastrics (AcLG) from the replaced left hepatic (ReLH) Celiac (CA) markedly constricted *at its root* (M N *adult*)

The volume of blood carried by the LG is unusually large It supplied the MH (for the quadrate lobe QL) and the LH (for the lateral segment of the left lobe) The umbilical fossa was opened by cutting the pons hepatis After crossing the junction point of the cystic duct (CD) with the hepatic duct (HD) the RH gives off the cystic (C) then divides into its anterior and posterior segmental branch (RIL) A branch of the RH passes behind the portal vein (PV) to supply the caudate process the right and the left parts of the caudate lobe (CL) proper

AcLG from the ReLH *are unusually large* and exhibit extensive anastomoses with the recurrent branch of left inferior phrenic (LIP) the short gastrics (SG) of the *splenic (S) and the cardio-esophageal (CE)* branches of the celiac LG The magistral type of the S proceeds to the hilus of the spleen where it breaks up into 11 lienal branches The superior polar (SP) anastomoses with the ReLH 3 inferior polars (IP) from the left gastro-epiploic (LGE) There are 2 superior pancreaticoduodenal *arteries (SPD)—one unites with the transverse* pancreatic (TP) which picked up the retroduodenal arcade made by the retroduodenal artery (RD) the other unites with the common inferior pancreaticoduodenal (IPD) via 2 branches and with a jejunal branch going to the first part of the jejunum The IP stems from the SPD and along its course anastomoses with the RD arcade the dorsal pancreatic (DP) from the H the large pancreatic (PM) from the S *and the caudal pancreatic (CP) from the* LGE The posterior epiploic (PE) from the TP to the transverse mesocolon (TrCol) The right inferior phrenic (RIP) from the right renal artery (RR) (frequent)

Collateral arterial pathways between (1) the LH and the S via the accessory left hepatic (AcLH) from the LH (2) the LH and the LIP via the CE branches (3) the RH and the LGE via the GD the TP and the DP (4) the GD and the S via the long TP (5) the RH and the superior mesenteric (SM) via the anterior and the posterior pancreaticoduodenal arcades CD 3 cm HD 3 cm CBD 7 cm

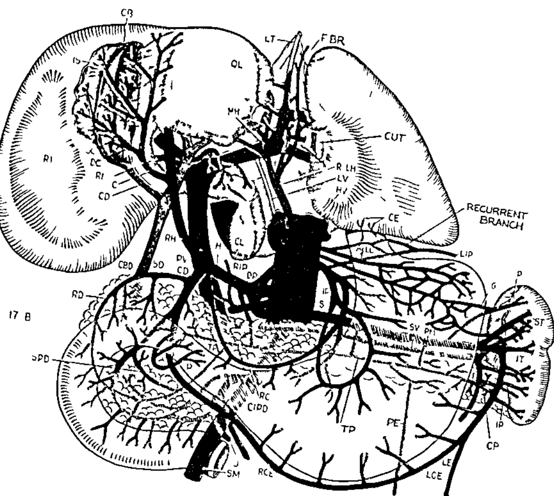

CB
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R LH
LV
HV
RECURRENT BRANCH
CE
RH
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CL
LIP
CBD
SD
PV
CD
RIP
DP
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17 B
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SPD
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RC
CIPD
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PE
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CP
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J
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RCE
LCE

FIGURE 48

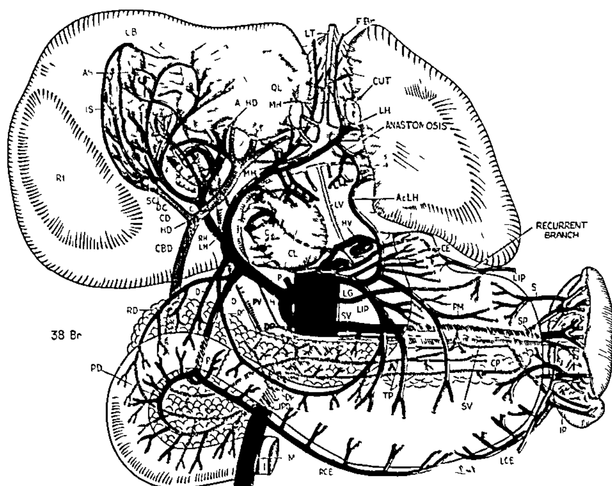


FIG 19 Complete hepatolienogastric celiac trunk (CTı) (25 mm x 8 mm) with an accessory left hepatic (AcLH) from the left gastric (LG) which was anastomosed with the left hepatic (LH) Single cystic (C) Accessory hepatic duct (AcHD) (M N 39 yrs)

The AcLH is anastomosed with the celiacal LH The anastomosis in the lesser omentum is a remnant of the primitive arc between the LG and the LH the lower part of the arc becoming an AcLH supplying the superior area of the lateral segment

The cystic triangle was opened widely to display vessel content The long C (10 mm x 2 mm) gives off 4 branches 3 of which pertain to the deep cystic (DC) one being a large liver artery anastomosed with the C Above the C is a long liver branch which could be mistaken for the C since it runs parallel with it The right hepatic (RH) divides into its anterior and posterior segmental branches The latter (arched) gives off a branch to the caudate process of the caudate lobe (CL) Of the 38 terminal branches dissected after the pons hepatis was cut 14 were associated with the blood supply of the CL The middle hepatic (MH) supplies 4 rami to the quadrate lobe (QL)

The supraduodenal (SD) arises with the right gastric (RG) from the hepatic (H) The common inferior pancreaticoduodenal (CIPD) from the superior mesenteric (SM) picks up the anterior and the posterior pancreaticoduodenal arcades made respectively by the retroduodenal (RD) and the superior pancreaticoduodenal (SPD) The dorsal pancreatic (DP) is double the lower one from the SM gives off 2 transverse pancreatics (TP) No major anastomosis between the right gastro epiploic (RGE) and the left gastro epiploic (LGE) The cardio-esophageal (CE) region of the stomach is supplied by CE branches from the LG the AcLH the recurrent branch of the left inferior phrenic (LIP) and by the short gastrics (SG) from the superior polar (SP)

The large AcHD crosses the cystic triangle and joins another duct emerging from the liver The long lower duct probably represents the posterior segmental duct while the short upper one represents the anterior segmental duct for the respective posterior and anterior segments of the right lobe union of 2 ducts having taken place outside the liver as seen in corrosion casts CD 3 cm HD 1 cm CBD

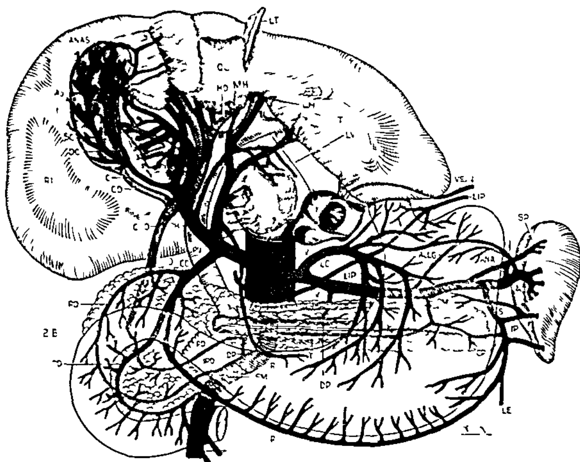


Fig 50 Typical pattern of the blood supply of the supramesocolonic organs The hepatolienogastric celiac trunk (CTr) with origin of the left gastric (LG) shifted to the splenic (S) which gives rise to another left gastric (AcLG) *the ramus esophagogastricus posterior ascendens* (M ∖ 51 yrs)

The cystic triangle was widened to display vessels in this area The right hepatic (RH) divides into anterior and posterior segmental arteries for anterior and posterior segments of the right lobe The long single cystic (C) runs parallel with the cystic duct (CD) and upon reaching the gallbladder (GP) divides into its superficial (SC) and deep branches (DC) *Twigs to the liver from the DC medial to the CB often are cryptically hidden and when cut in cholecystectomy retract into the liver and bleed* The left hepatic (LH) gives off the middle hepatic (MH) for the quadrate lobe (QL) the caudate lobe (CL) receives an independent branch from the RH Each pancreaticoduodenal arcade sends branches to the duodenum and the pancreatic tissue and joins the superior mesenteric (SM) via its own inferior pancreaticoduodenal (IPD)

Two supraduodenal arteries (SD) one from the gastroduodenal (GD) the other from the retroduodenal (RD) both supply the first part of the duodenum one supplies the common bile duct (CBD) The dorsal pancreatic (DP) from the SM gives off the transverse pancreatic (TP) which anastomoses with the large pancreatic (PM) of the S and the caudal pancreatic (CP) of the left gastroepiploic (LGE) It supplies the pancreatic duct which accompanies it

The cardio-esophageal end of the stomach is supplied by branches (CE) of the LC the recurrent branch of the left inferior phrenic (LIP) the AcLC and by short gastrics (SG) one of which is anastomosed with the LG *The transverse anastomosis between the superior polar (SP) and the splenic trunk is the last extraorganal anastomosis between the lienal branches for inside the spleen there is no anastomosis between the major arteries* The lower pole of the spleen receives 2 inferior polars (IP) from the LGE

The CD is tied to the hepatic duct (HD) for 1 cm and opens posteriorly The HD shows its right and left branches the latter receiving drainage from the QL. CD 1 5 cm HD 5 cm CBD 7 cm

FIG 49 Complete hepatolienogastric celiac trunk (CTr) (25 mm x 8 mm) with an accessory left hepatic (AcLH) from the left gastric (LG) which was anastomosed with the left hepatic (LH) Single cystic (C) Accessory hepatic duct (AcHD) (M N 39 yrs)

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The large AcHD crosses the cystic triangle and joins another duct emerging from the liver The long lower duct probably represents the posterior segmental duct while the short upper one represents the anterior segmental duct for the respective posterior and anterior segments of the right lobe union of 2 ducts having taken place outside the liver as seen in corrosion casts CD 3 cm HD 1 cm CBD 9 cm

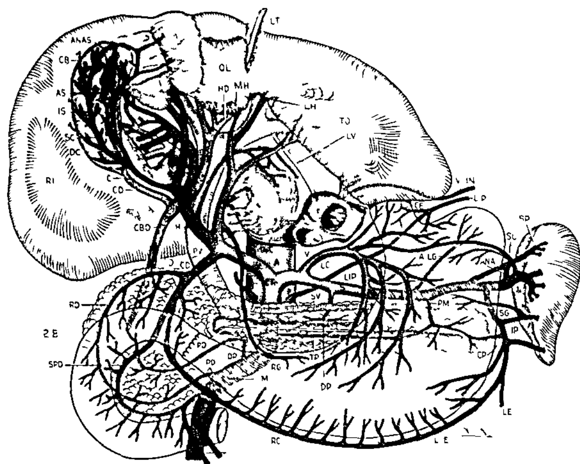


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The CD is tied to the hepatic duct (HD) for 1 cm and opens posteriorly The HD shows its right and left branches the latter receiving drainage from the QL CD 1 5 cm HD 5 cm CBD 7 cm

Fig 51 A complete hepatolienogastric trunk with the 3 hepatics (right RH middle MH and left LH) arising from the hepatic (H) the LH from the celiac (CTr) Additional celiac branches here are a second splenic artery an accessory left gastric (AcLG) and a communicating branch to the retroduodenal (RD) Single cystic (C) (M W 82 yrs)

A double S *(arteria splenica secunda)* occurs very rarely (2 cases in 500 bodies) The second S (5 mm wide) is but a long *superior polar artery (SP)* which instead of arising from the first part of the S takes origin directly from the CTr The main S is 12 cm long and markedly tortuous

The RH makes a characteristic caterpillarlike loop downward toward the cystic duct (CD) the loop being crossed by the C The duodenum is turned forward to show the copious blood supply on the *back of the pancreas and the duodenum made by the RD* as it forms the posterior pancreaticoduodenal arcade Crossing the common bile duct (CBD) it sends branches to it and to all 3 parts of the duodenum and unites with the superior mesenteric (SM) via its own inferior pancreaticoduodenal (IPD) It communicates with the celiac trunk (CTr) the right gastric (RG) and the supraduodenal (SD) The SD here arises from the *H proper and is anastomosed* with the gastroduodenal (GD) and the RG showing it not to be an *end artery,* as claimed by Wilkie The anterior pancreaticoduodenal arcade ends in the IPD derived from the SM at a lower point

The right gastro epiploic (RGE) and the *middle colic (MCol)* arise from the SM via a common trunk Otherwise stated the gastric (RGE) and the pancreaticoduodenal blood supplies here are anastomosed with the MCol via a large branch which is united with the dorsal pancreatic (DP) from the common hepatic and with the transverse pancreatic (TP) The left gastro-epiploic (LGE) from the inferior splenic terminal (IT) gives off an inferior polar (IP) to the spleen and is anastomosed with the RGE The S is long (12 cm) and tortuous this condition being prevalent in *aged individuals* (over 50 yrs) and absent in the young Large anastomosis between the LH and the RH with blood supply to the caudate process The caudate lobe proper (CL) receives a branch of the RH that passes dorsal to the left branch of the portal vein (PV) The falciform branches from the LH are continued into the falciform ligament where they anastomose with branches of the internal mammary The CTr is 40 mm long and tapered at the beginning CD 3 cm HD 3 cm CBD 8 cm

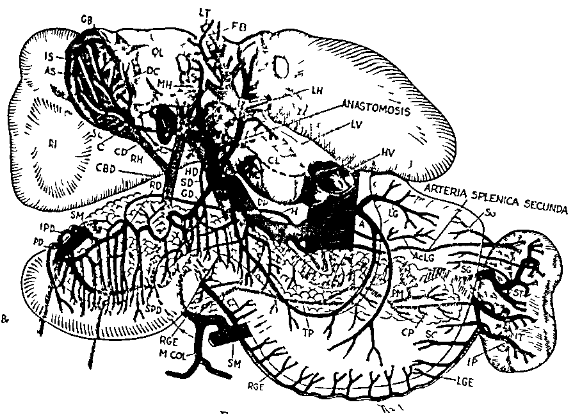

GB
LT
FB
IS
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QL
DC
MH
LH
ANASTOMOSIS
LV
RI
C
CD
RH
CBD
HV
CL
HD
SD
GD
RD
DP
H
ARTERIA SPLENICA SECUNDA
SM
IPD
PD
A
LG
AcLG
SG
ST
PM
IT
SPD
CP
SC
IP
TP
RGE
M COL
SM
RGE
LGE

FIGURE 51

Fig 52 Typical pattern of the blood supply of the supramesocolonic organs the right hepatic (RH) crossing the hepatic duct (HD) anteriorly (12%) *Complete hepatolienogastric celiac trunk (CTr) Single cystic (M W 56 yrs)*

After giving *off the gastroduodenal* (GD) the common hepatic becomes the hepatic artery (*H*) which *divides into its typical 3* branches the right (RH) the middle (MH) and the left (LH) hepatics *28* hepatic terminal branches enter the liver many running a ***subcapsular course*** Note the downward caterpillarlike loop made by the RH as it crosses the HD anteriorly and enters the cystic triangle where it would have been subject to surgical harm After a course of 3 cm the cystic artery (C) divides into its superficial (SC) and deep (DC) branches the two being anastomosed distally Both branches give off liver twigs After supplying the caudate lobe (CL) proper and one half of the caudate process the LH divides into the superior and the inferior area arteries of the lateral segment of the left lobe as judged from casts The first half of the caudate process is supplied by a branch of the RH

A coiled portion of the tortuous splenic (S) gives rise to an accessory left gastric (AcLG)—*the ramus esophagogastricus posterior ascendens*—distributed to the fundic region of the stomach where it unites with short gastrics (SG) from the splenic terminals *Selective distribution of the lienal* branches to the notched areas of the spleen there being 2 *inferior polar* (*IP*) arteries The left gastro epiploic (LGE) arises from the inferior terminal branch of the S The right gastro-epiploic (RGE) is not anastomosed with the LGE at the greater curvature but an anastomosis between the two vessels is effected via the arc of Barkow the limbs of the arc being the right and the left epiploic branches (RE LE) of the respective vessels The tail of the pancreas is supplied by the a pancreatica magna (PM) from the S and the caudal pancreatic (CP) from the LGE Communicating with the latter 2 vessels is the transverse pancreatic (TP) which to the right comes to the ventral surface of the pancreas where it unites with the GD and via deeper branches with the retroduodenal (RD) and the superior mesenteric (SM) The dorsal pancreatic (DP) from the SM

The duodenum is turned forward displaying the primary and the secondary arcades made by the retroduodenal artery (RD) A posterior branch of the superior pancreaticoduodenal (SPD) picks up the RD a conjoined vessel forming a common inferior pancreaticoduodenal (IPD) that joins the SM The supraduodenal (SD) is *not an end artery* as it forms scalloping loops with the RD The biliary tract receives its blood supply from the C the RD and the SD *CD* 3 cm HD 4 cm CBD 9 cm

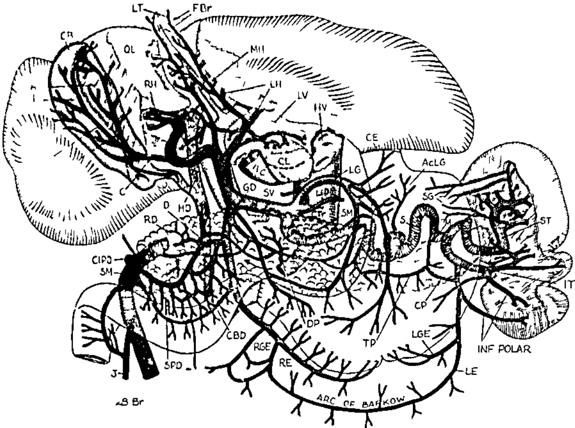

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Figure 52

FIG 52 Typical pattern of the blood supply of the supramesocolonic organs the right hepatic (RH) crossing the hepatic duct (HD) anteriorly (12%) Complete hepatolienogastric celiac trunk (CTr) Single cystic (M W 56 yrs)

After giving off the gastroduodenal (GD) the common hepatic becomes the hepatic artery (H) which divides into its typical 3 branches the right (RH) the middle (MH) *and the left (LH) hepatics 28 hepatic terminal* branches enter the liver many running a *subcapsular course* Note the downward *caterpillarlike loop made by the RH* as it crosses the HD anteriorly and enters the cystic triangle where it would have been subject to surgical harm After a course of 3 cm the cystic artery (C) divides into its superficial (SC) and deep (DC) branches the two being anastomosed distally Both branches give off liver twigs After supplying the caudate lobe (CL) proper and one half of the caudate process the LH divides into the superior and the inferior area arteries of the lateral segment of the left lobe as judged from casts The first half of the caudate process is supplied by a branch of the RH

A coiled portion of the tortuous splenic (S) gives rise to an accessory left gastric (AcLG)—*the ramus esophagogastricus posterior ascendens*—distributed to the fundic region of the stomach where it unites with *short gastrics (SG) from the splenic terminals* Selective distribution of the lienal branches to the notched areas of the spleen there being 2 inferior polar (IP) arteries The left gastro epiploic (LGE) arises from the inferior terminal branch of the S The right gastro-epiploic (RGE) is not anastomosed with the LGE at the greater curvature *but an anastomosis between the two* vessels is effected via the arc of Barkow the limbs of the arc being the right and the left *epiploic branches (RE LE) of the respective* vessels The tail of the pancreas is supplied by the a pancreatica magna (PM) from the S and the caudal pancreatic (CP) from the LGE Communicating with the latter 2 vessels is the transverse pancreatic (TP) which to the right comes to the ventral surface of the pancreas where it unites with the GD and via deeper branches with the retroduodenal (RD) and the superior mesenteric (SM) The dorsal pancreatic (DP) from the SM

The duodenum is turned forward displaying the primary and the secondary arcades made by the retroduodenal artery (RD) A posterior branch of the superior pancreaticoduodenal (SPD) picks up the RD a conjoined vessel forming a common inferior pancreaticoduodenal (IPD) that joins the SM The supraduodenal (SD) is *not an end artery* as it forms scalloping loops with the RD The biliary tract receives its blood supply from the C the RD and the SD CD 3 cm HD 1 cm CBD 9 cm

Figure 52

Fig 52 Typical pattern of the blood supply of the supramesocolonic organs the right hepatic (RH) crossing the hepatic duct (HD) anteriorly (12%) Complete hepatolienogastric celiac trunk (CTr) Single cystic (M W 56 yrs)

After giving off the gastroduodenal (GD) the common hepatic becomes the hepatic artery (H) which divides into its typical 3 branches the right (RH), the middle (MH) and the left (LH) hepatics 28 hepatic terminal branches enter the liver many running a *subcapsular course* *Note the downward* caterpillarlike loop made by the RH as it crosses the HD anteriorly and enters the cystic triangle where it would have been subject to surgical harm After a course of 3 cm the cystic artery (C) divides into its superficial (SC) and deep (DC) branches *the two being anastomosed distally Both* branches give off liver twigs After supplying the caudate lobe (CL) proper and one half of the caudate process the LH divides into the superior and the inferior area arteries of the lateral segment of the left lobe as judged from casts The first half of the caudate process is supplied by a branch of the RH

A coiled portion of the tortuous splenic (S) gives rise to an accessory left gastric (AcLG)—*the ramus esophagogastricus posterior ascendens*—distributed to the fundic region of the stomach where it unites with short gastrics (SG) from the splenic terminals Selective distribution of the lienal branches to the notched areas of the spleen there being 2 inferior polar (IP) arteries The left gastro epiploic (LGE) arises from the inferior terminal branch of the S The right gastro-epiploic (RGE) is not anastomosed with the LGE at the greater curvature but an anastomosis between the two vessels is effected via the arc of Barkow the limbs of the arc being the right and the left epiploic branches (RE LE) of the respective vessels The tail of the pancreas is supplied by the a pancreatica magna (PM) from the S and the caudal pancreatic (CP) from the LGE Communicating with the latter 2 vessels is the transverse pancreatic (TP) which to the right comes to the ventral surface of the pancreas where it unites with the GD and via deeper branches with the retroduodenal *(RD) and the superior mesenteric* (SM) The dorsal pancreatic (DP) from the SM

The duodenum is turned forward displaying the primary and the secondary arcades made by the retroduodenal artery (RD) A posterior branch of the superior pancreaticoduodenal (SPD) picks up the RD a conjoined vessel forming a common inferior pancreaticoduodenal (IPD) that joins the SM The supraduodenal (SD) is *not an end artery* as it forms scalloping loops with the RD The biliary tract receives its blood supply from the C the RD and the SD CD *3 cm HD 4 cm CBD 9 cm*

Figure 53

Fig 53 Celiacal hepatic absent The entire hepatic artery (*ReHTr*) arises (i e is replaced) from the superior mesenteric (SM) constituting a hepatomesenteric trunk (5 cases) The left gastric (LG) and the splenic (S) arise jointly from a lienogastric celiac trunk Single cystic (C) (M N 35 yrs)

The common hepatic (ReHTr) arises from the SM and passes through the head of the pancreas a point to be remembered in *every pancreaticoduodenal resection,* lest by an unintentional severance of such a hepatic the patient die during the operation The H (8 cm long) divides into the right (RH) and the left (LH) branches these being *replaced hepatics Middle hepatic (MH) from RH* The gastroduodenal (GD) is very short Note the large pyloric branch from the superior pancreaticoduodenal (SPD)

The replaced right hepatic (ReRH) after crossing the hepatic duct (HD) anteriorly (12%) makes a downward caterpillarlike loop in the cystic triangle then passes upward to swerve around a large accessory hepatic duct (AcHD *2* cm long 5 mm wide) which most probably represents a segmental duct from the posterior segment of the right lobe it having failed to unite with the anterior segmental duct The C divides nearly immediately into its superficial (SC) and deep (DC) branches This illustrates 4 surgical hazards (1) short C (2) looped RH (3) AcHD (4) ReHTr from the SM The gallbladder (*GB*) was *very small (5 cm x 2 cm*) A dense plexus of nerves about the common bile duct (CBD) and the lymph node of Luschka (LN) (ganglion of Terrier) often renders supraduodenal approach to the CBD a tedious and difficult task The nature of the nerves is largely unknown

The transverse pancreatic (TP) arises from the SM and is anastomosed with the dorsal pancreatics (DP) (which here are dual) the a pancreatica magna (PM) from the S and the caudal pancreatic (CP) from the left gastroepiploic (LGE) to the left and to the right is united with the right gastro-epiploic (RGE) The TP gives off a large posterior epiploic branch (PE) as an accessory middle colic (AcMCol) to the left colic flexure The anterior and the posterior pancreaticoduodenal arcades unite with the SM via a common inferior pancreaticoduodenal (IPD) Branches of the latter pass under the SM to supply the *critically vascularized duodenojejunal junction that should always be inspected in regional resections* The retroduodenal (RD) supplies ascending branches to the CBD The S magistral in type proceeds nearly to the hilus of the spleen before breaking up into its superior and inferior terminal branches (ST IT) The LG is anastomosed with the LH by a small vessel a remnant of the primitive embryonic union between the 2 arteries

The caudate lobe (CL) proper is supplied by the replaced left hepatic (ReLH) the caudate process by the MH and a branch of the ReRH the latter passing behind the *portal vein (PV)* CD 2 cm HD 3 cm CBD 8 cm

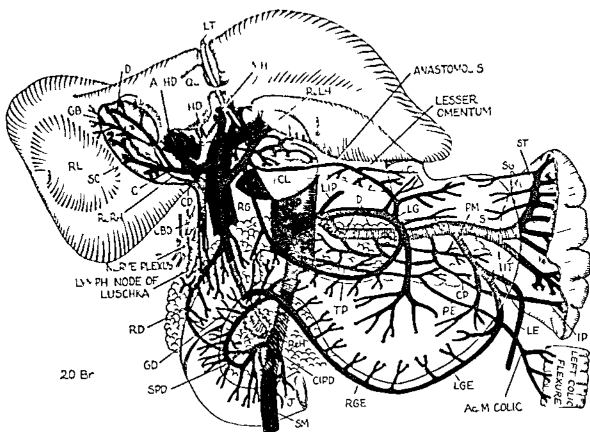

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FLEXURE

FIGURE 53

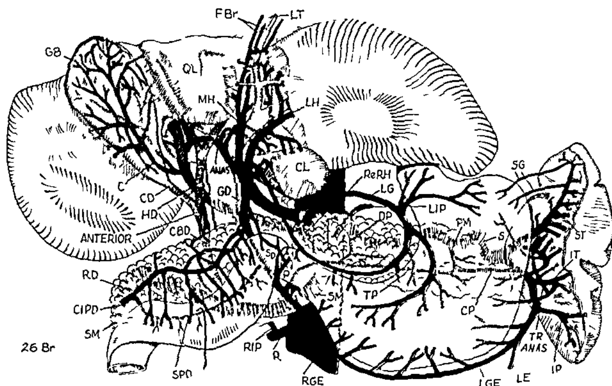


FIG 51 Aberrant origin of the right hepatic (ReRH) as the first branch of the celiac the ReRH here giving rise to the left gastric (LG) coursing dorsal to the portal vein (PV) and being anastomosed with the left hepatic (LH) Single cystic (C) (M W 69 yrs)

Origin of the LG from the first part of the replaced right hepatic (ReRH) is odd and occurs very rarely Anastomosis between the ReRH and the LH is one of the largest seen The stem of the C is very short and arises from the *left side* of the ReRH not an uncommon phenomenon The duodenum is turned forward displaying a retroduodenal arcade made by the retroduodenal (RD) artery The anterior and the posterior pancreaticoduodenal arcades unite with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) The transverse pancreatic (TP) arises from the right gastroepiploic (RGE) and along its course on the inferior surface of the pancreas anastomoses with the dorsal pancreatic (DP) and the a pancreatica magna (PM) from the splenic (S) and with the caudal pancreatic (CP) from the left gastro epiploic (LGE) The supraduodenal (SD) communicates with a pyloric branch (P) of the RGE and with the RD

The lobulated spleen is vascularized along its entire hilar surface by 21 lienal branches The *transverse anastomosis* between the superior terminal (ST) and the inferior terminal (IT) via lienal branches at the hilus constitutes the last instance of anastomosis between the lienal branches *there being none inside the spleen—all intrasplenic arteries being end arteries* So likewise all intrahepatic arteries are end arteries there being no anastomosis between them

The caudate lobe proper (CL) is supplied by a branch of the LH the caudate process by rami from a vessel uniting the ReRH and the middle hepatic (MH) Falciform branches from the MH coursing in the falciform ligament anastomose with the ensiform branch of the internal mammary thereby constituting a collateral pathway to the liver from vessels above the diaphragm The left inferior phrenic (LIP) from the aorta (A) the right inferior phrenic (RIP) from the renal artery a frequent phenomenon The cystic duct (CD) opens anteriorly its mode of union with the hepatic duct (HD) being the angular type The common bile duct (CBD) tapers in its intrapancreatic course and receives a blood supply from the RD CD 3 cm HD 1 cm CBD 1 5 cm

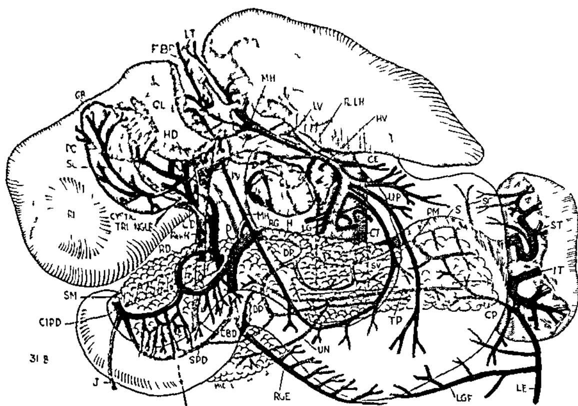


Fig 55 Both the right and the left hepatic are replaced the right hepatic (ReRH) from the superior mesenteric (SM) the left hepatic (ReLH) from the left gastric (LG) there being no celiac hepatic branch present except a small middle hepatic (MH) given off by the gastroduodenal (GD) along with the right gastric (RG) Dual cystics (C) (M W 78 yrs)

A replaced right hepatic (ReRH) from the superior mesenteric (SM) gives off a liver branch to the fissured area in the confines of the cystic triangle which could have been mistaken for the C The C is double i e its superficial (SC) and deep (DC) branches have a separate albeit close origin from the ReRH *Tying of the DC should be effected distal to its 2 liver branches to prevent bleeding* The caudate lobe (CL) is supplied by a branch of the ReRH that communicates with the ReLH The latter gives off the MH for the quadrate lobe (QL) and 2 falciform branches to the falciform ligament

The duodenum is turned forward to show the retroduodenal (RD) and its arcades One arcade loops around the common bile duct (CBD) to unite with the ReRH the other joins the SM via a common inferior pancreaticoduodenal (IPD) a posterior branch of which picks up the superior pancreaticoduodenal (SPD) that forms the anterior pancreaticoduodenal arcade The dorsal pancreatic (DP) arises from the first part of the splenic (S) and passes under the portal vein (PV) near the junction of the superior mesenteric vein (SMV) and the splenic vein (SV) To the left it gives off the transverse pancreatic (TP) that unites with the a pancreatica magna (PM) from the S and the caudal pancreatic (CP) from the left gastroepiploic (LGE) thereby effecting a collateral pathway for the S One right branch of the DP joins the SPD another supplies the uncinate process (Un) of the pancreas Before passing under the SV the DP gives off a branch that crosses anterior to the vein and nearing the ventral surface of the pancreas communicates with the S

Of 31 branches entering the liver the QL receives 7 the CL 10 Celiac artery (CTr) 20 mm long 10 mm wide CD 2 5 cm HD 3 cm CBD 7 cm

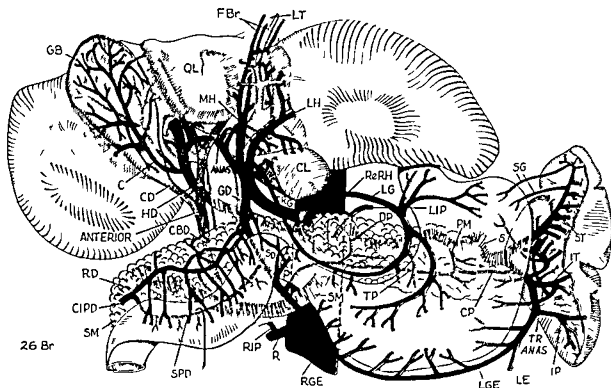


FIG 51 Aberrant origin of the right hepatic (ReRH) as the first branch of the celiac the ReRH here giving rise to the left gastric (LG) coursing dorsal to the portal vein (PV) and being anastomosed with the left hepatic (LH) Single cystic (C) (M W 60 yrs)

Origin of the LG from the first part of the replaced right hepatic (ReRH) is odd and occurs very rarely Anastomosis between the ReRH and the LH is one of the largest seen The stem of the C is very short and arises from the *left side* of the ReRH not an uncommon phenomenon The duodenum is turned forward displaying a retroduodenal arcade made by the retroduodenal (RD) artery The anterior and the posterior pancreaticoduodenal arcades unite with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) The transverse pancreatic (TP) arises from the right gastroepiploic (RGE) and along its course on the inferior surface of the pancreas anastomoses with the dorsal pancreatic (DP) and the a pancreatica magna (PM) from the splenic (S) and with the caudal pancreatic (CP) from the left gastro epiploic (LGE) The supra duodenal (SD) communicates with a pyloric branch (P) of the RGE and with the RD

The lobulated spleen is vascularized along its entire hilar surface by 21 lienal branches The *transverse anastomosis* between the superior terminal (ST) and the inferior terminal (IT) via lienal branches at the hilus constitutes the last instance of anastomosis between the lienal branches *there being none inside the spleen—all intrasplenic arteries being end arteries* So likewise all intrahepatic arteries are end arteries there being no anastomosis between them

The caudate lobe proper (CL) is supplied by a branch of the LH the caudate process by rami from a vessel uniting the ReRH and the middle hepatic (MH) Falciform branches from the MH coursing in the falciform ligament anastomose with the ensiform branch of the internal mammary thereby constituting a collateral pathway to the liver from vessels above the diaphragm The left inferior phrenic (LIP) from the aorta (A) the right inferior phrenic (RIP) from the renal artery a frequent phenomenon The cystic duct (CD) opens anteriorly its mode of union with the hepatic duct (HD) being the angular type The common bile duct (CBD) tapers in its intrapancreatic course and receives a blood supply from the RD CD 3 cm HD 1 cm CBD 1 5 cm

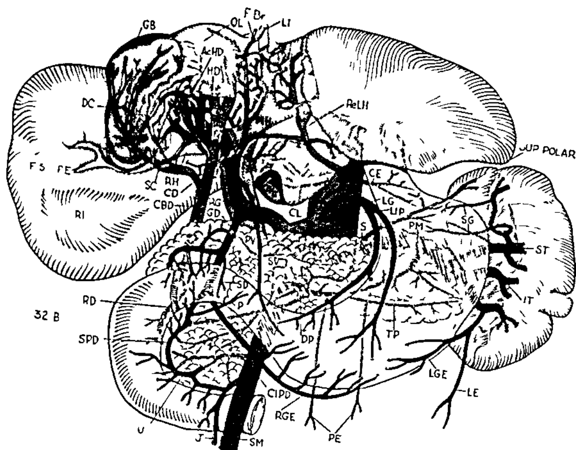


FIG 57 Incomplete hepatolienogastric trunk (CTr) with left hepatic (ReLH) replaced from the left gastric (LG) Double cystic artery both with origin in Calot's triangle Accessory hepatic duct (AcHD) (M W 58 yrs)

The cystic triangle presents the following surgical hazards (1) an adjacent fissured area supplied by a long cystic like artery (2) 2 large hepatic branches of the right hepatic (RH) the lower (probably the posterior segmental) giving off the superficial cystic (SC) that leaves the triangle by swinging around the cystic duct (CD) the upper (probably the anterior segmental) giving off the deep cystic (DC) that is largely hidden (3) an AcHD 2 mm wide that crosses the lower branch of the RH at a higher point but is crossed by the DC

The caudate lobe (CL) is supplied by a branch of the RH that passes behind the portal vein (PV) and by a branch of the middle hepatic (MH) the two being anastomosed The ReLH sends a branch to the quadrate lobe (QL) The retroduodenal (RD) makes a loop around the common bile duct (CBD) and forms the posterior pancreaticoduodenal arcade A posterior branch of the anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) picks up the posterior arcade and the two become united with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) Subsidiary connections are effected with *a jejunal branch and with the dorsal pancreatic (DP) The DP here arises from the SM* and exhibits its characteristic 3 branches the transverse pancreatic (TP) to the left one right branch that joins the SPD another right branch that supplies the uncinate process (Un) The TP gives off 2 posterior epiploics (PE) and unites with the a pancreatica magna (PM) from the splenic (S) The long superior polar from the S to the upper splenic tubercle gives off gastric and cardio-esophageal branches the latter uniting with similar branches from the ReLH thereby effecting a collateral path way to liver via the S when the hepatic (H) is ligated

The left gastro-epiploic (LGE) falls short of the right gastro-epiploic (RGE) (10%) It arises from the inferior splenic terminal (IT) Celiac artery (CTr) 25 mm x 11 mm Interval from CTr to SM on aorta 1 mm CD 3 cm HD 4 cm CBD 6 5 cm

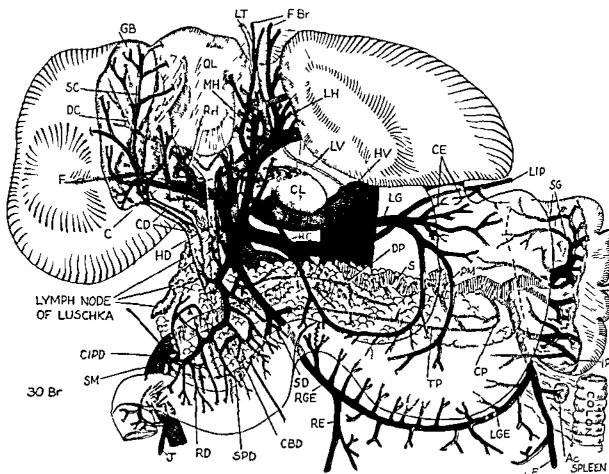


FIG 56 Origin of the superior mesenteric artery (SM) from the celiac artery constituting a hepatolienomesenteric trunk Separate origin of the left gastric (LG) from the aorta Long parallel type of cystic duct (CD) Accessory spleen in gastrocolic ligament (M W 67 yrs)

This very odd type of origin of hepatic (H) splenic (S) and SM from the common trunk was seen but once in 200 bodies The type *is not to be confused with a celiaco mesenteric trunk where the SM arises in conjunction with the celiac such a trunk also being very rare (2 cases)* The stem of the cystic artery (C) is very short (1 cm) Its superficial (SC) and deep (DC) branches send twigs to the CD The latter was very long and was united intimately with the hepatic duct (HD) for 3 cm before opening into the common bile duct (CBD) The lymph node of Luschka or ganglion of Terrier (Belou 1915) completely surrounded the lower portion of the biliary tract most of it being behind the junction point of the CD with the HD The common H trifurcated as it often does the right hepatic (RH) the left hepatic (LH) and the gastroduodenal (GD) arising from the same point

The duodenum is turned forward displaying the retroduodenal arcade and the manner in which it supplies the CBD the pancreas and all 3 parts of the dorsal wall of the duodenum The arcade is united with the supraduodenal (SD) a branch of the GD and the dorsal pancreatic (DP) a branch of the S Cardiac esophageal branches (CE) from the left inferior phrenic (LIP) unite with similar branches from the LG and with short gastrics (SG) from the S The transverse pancreatic (TP) stems from the GD at the tail of the pancreas it unites with the a pancreatica magna (PM) and the caudal pancreatic (CP) the latter here a branch of the S *Note the selective distribution of the terminal lienal branches to the notched areas of the spleen* The accessory spleen (1 cm) in the gastrocolic ligament is supplied by a branch of the left epiploic (LE) The right and the left epiploics (RE LE) represent the respective limbs of the arc of Barkow found in the posterior layer of the great omentum The caudate lobe proper (CL) is supplied by a branch from the LH the caudate process by a branch from the RH The inferior phrenics (I IP) arise from the LG CD 7 cm long (3 cm joined to the HD) HD 6 cm CBD 4 cm

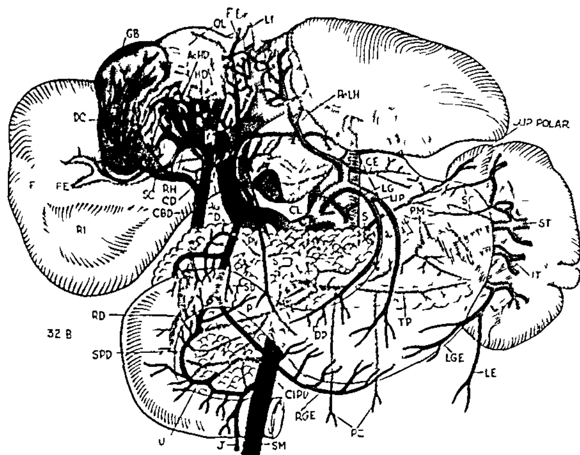


Fig 57 Incomplete hepatolienogastric trunk (CTr) with left hepatic (ReLH) replaced from the left gastric (LG). Double cystic artery both with origin in Calot's triangle. Accessory hepatic duct (AcHD) (M W 58 yrs)

The cystic triangle presents the following surgical hazards (1) an adjacent fissured area supplied by a long cystic like artery (2) 2 large hepatic branches of the right hepatic (RH) the lower (probably the posterior segmental) giving off the superficial cystic (SC) that leaves the triangle by swinging around the cystic duct (CD) the upper (probably the anterior segmental) giving off the deep cystic (DC) that is largely hidden (3) an AcHD 2 mm wide that crosses the lower branch of the RH at a higher point but is crossed by the DC.

The caudate lobe (CL) is supplied by a branch of the RH that passes behind the portal vein (PV) and by a branch of the middle hepatic (MH) the two being anastomosed. The ReLH sends a branch to the quadrate lobe (QL). The retroduodenal (RD) makes a loop around the common bile duct (CBD) and forms the posterior pancreaticoduodenal arcade. A posterior branch of the anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) picks up the posterior arcade and the two become united with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD). Subsidiary connections are effected with *a jejunal branch and with the dorsal pancreatic (DP). The DP here arises from the* SM and exhibits its characteristic 3 branches the transverse pancreatic (TP) to the left one right branch that joins the SPD another right branch that supplies the uncinate process (Un). The TP gives off 2 posterior epiploics (PE) and unites with the a. pancreatica magna (PM) from the splenic (S). The long superior polar from the S to the upper splenic tubercle gives off gastric and cardio-esophageal branches the latter uniting with similar branches from the ReLH thereby effecting a collateral pathway to liver via the S when the hepatic (H) is ligated.

The left gastro-epiploic (LGE) falls short of the right gastro-epiploic (RGE) (10%). It arises from the inferior splenic terminal (IT). Celiac artery (CTr) 25 mm x 11 mm. Interval from CTr to SM on aorta 1 mm. CD [illegible] cm HD 1 cm CBD 6.5 cm

Fig 58 An accessory right hepatic (AcRH) from the superior mesenteric (SM) which in its ascent to the cystic triangle is closely related to the cystic duct (CD) passing behind it Complete hepatolienogastric celiac trunk (CTr) A huge accessory hepatic duct (AcHD) receives the CD posterolaterally (M W 60 yrs)

The huge AcHD (3 5 cm long 3 mm wide) most probably represents an instance in which the posterior segmental duct of the posterior segment of the right lobe joined the hepatic duct (HD) outside the liver In other words the anterior and the posterior *segmental ducts of the right lobe failed to* unite inside the liver to constitute the right HD Two right hepatics (RH) of which the AcRH from the superior mesenteric (SM) (1 cm long) most probably represents the artery supplying the posterior segment of the right lobe the anterior segment being supplied by the RH from the celiac (CTr) The AcRH from the SM (partly hidden by the ganglion or lymph node of Terrier) gives off a liver branch and *the entire cystic artery (C)*

The duodenum has been turned forward to show the distribution of the retroduodenal artery (RD) and its arcades on the posterior surface of the duodenum and the head of the pancreas Twigs from the RD supply the common duct (CBD) The anterior pancreaticoduodenal arcade is double one *superior pancreaticoduodenal (SPD)* takes origin from the gastroduodenal (GD) and ends in a common inferior pancreaticoduodenal (IPD) the other SPD takes origin from the right gastro-epiploic (RGE) passes under the superior mesenteric vein (SMV) and joins the SM separately Two supraduodenal arteries (SD) one arising to the left the other to the right of the GD Two transverse pancreatic arteries (TP) take origin from one of the SPD The upper runs along ventral surface of the pancreas and unites with the a pancreatica magna (PM) the lower courses along the inferior surface to unite with the dorsal pancreatic (DP) in the neck region and with the PM and the caudal pancreatic (CP) at the tail of the pancreas *No major anastomosis between the RGE and the left gastro epiploic (LGE)* The RG arises low (viz from the CD)

The caudate lobe (CL) is supplied by a branch of the RH that passes under the portal vein (PV) CA 20 mm long 7 mm wide CD opens *posteriorly into a huge* AcHD the opening for the HD being lower Intrahepatic part of the CBD markedly tapered CD 2 5 cm HD 1 cm CBD 7 cm

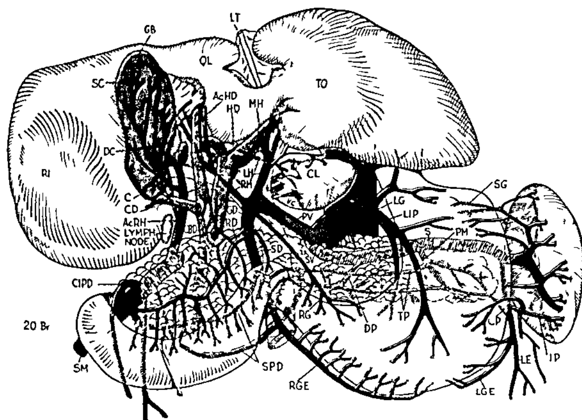

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FIGURE 58

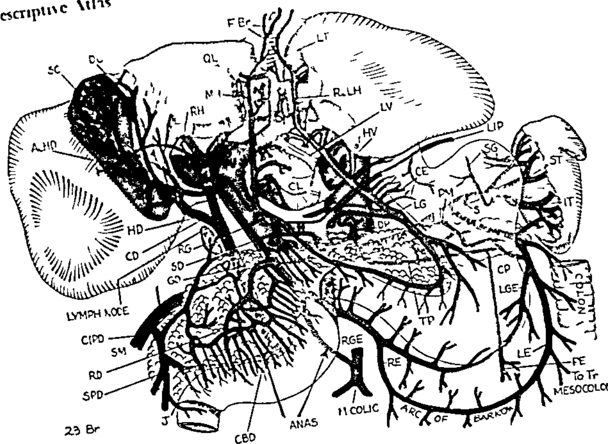
Fig 59 Origin of the cystic artery (C) *outside* the cystic triangle to the left of the hepatic duct (HD) from the celiac right hepatic (RH) (13%) Blood supply to the left lobe from the left gastric (LG) via a replaced left hepatic (ReLH) Subvesicular accessory hepatic duct (AcHD) (M W 63 yrs)

The common hepatic (H) divides into the RH and the gastroduodenal (GD) permitting the blood supply of the left lobe to come from the LG The middle hepatic (MH) and the right gastric (RG) arise from a common stem derived from the RH Following the terminology of Healey and Schroy the RH divides into its anterior and posterior segmental branches of the right lobe the replaced left hepatic (ReLH) into its superior and inferior area arteries of the lateral segment of the left lobe The positions of these arteries in the drawing are *reversed since the visceral surface* is shown

The C crosses the HD anteriorly The ReLH sends a branch under the ligamentum teres (LT) as a regional supply to the quadrate lobe (QL) its main supply coming from the MH Note the *filamentous subvesicular duct* often found coursing through the gall bladder (GB) bed Because of its stringlike appearance in a cholecystectomy it could be mistaken for *a nerve or a tissue fiber* and thus readily be torn causing postoperative leakage of bile and jaundice Its incidence is 33 per cent Healey and Schroy) Note likewise the ganglion of Terrier or the lymph node of Luschka (LN) that often surrounds the junction point of the cystic duct (CD) with the HD

The duodenum is turned forward displaying 2 retroduodenal arcades One made by the retroduodenal (RD) supplies the first and the second parts of the duodenum the other made by a branch of the dorsal pancreatic (DP) of celiac origin supplies the third part of the duodenum The 2 arcades join the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) the latter receiving the anterior arcade made by the superior pancreaticoduodenal (SPD) *The middle colic (MCol) is anastomosed with the GD De facto it may arise from the CD several cases of such origin having been observed* The supraduodenal (SD) forms a scalloping loop with the RG from which a shower of twigs is given off to the first inch of the duodenum The transverse pancreatic (TP) from the DP unites with the a pancreatica magna (PM) and the caudal pancreatic (CP) The left gastro-epiploic (LGE) is *not anastomosed* with the right gastro-epiploic (RGE) along the greater curvature but communicates with it via the arc of Barkow made by the right epiploic (RE) and the left epiploic (LE)

The caudate lobe (CL) is supplied by a branch of the MH the caudate process by a branch of the RH The blood supply of the abdominal esophagus comes from 3 sources cardio-esophageal branches (CE) from a recurrent branch of the left inferior phrenic (LIP) the LG and the short gastrics (SG) CD 2 5 cm HD 4 cm CBD 7 cm



F Br
LT
QL
Du
SC
R.LH
LV
RH
HV
LIP
AJHD
SG
ST
CE
CL
LG
IT
S
DP
HD
CD
RG
SD
GD
CP
LGE
LYMPH NODE
TP
CIPD
SM
RGE
LE
RD
RE
FE
To Tr
SPD
MESOCOLON
J
ANAS
M COLIC
ARC OF BARKOW
CBD
23 Br

FIGURE 59

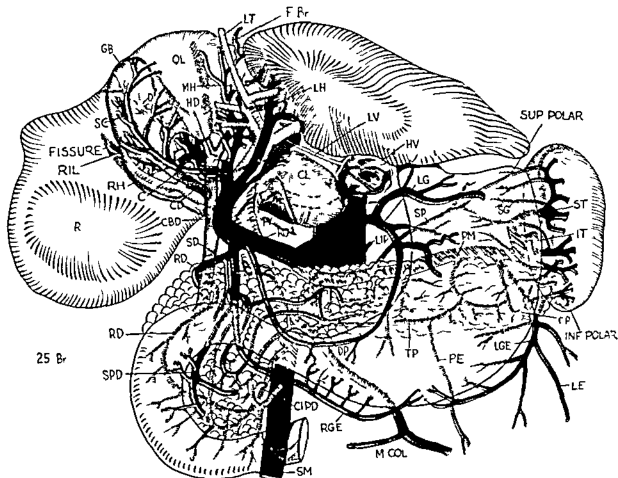


Fig 60 Typical pattern of the blood supply of the supramesocolonic organs Complete hepatolienogastric celiac trunk (CTr) with the left gastric (LG) as the first branch the hepatic proper (H) giving off the right (RH) the middle (MH) and the left (LH) hepatic Single cystic (C) with superficial (SC) and deep (DC) branches (M N 65 yrs)

The C arises from the RH to the left of the hepatic duct (HD) i e *outside the angle made by the cystic duct (CD) and the HD (Calot s triangle)* A branch of the right hepatic (RIL) probably the posterior segmental branch enters the fissured area below the gallbladder (GB) Upon deep probing of the omental tissue covering it it may be exposed and be mistaken for the cystic is demonstrated by the author in his exhibit of 100 cadaver specimens at A M A Convention Atlantic City 1947

The retroduodenal (RD) after crossing the common bile duct (CBD) anteriorly swings laterally and downward to pass behind the intrapancreatic portion of the CBD which it supplies with twigs The arcade made by the RD on the posterior surface of the head of the pancreas sends branches (7 to 10) to the back of the duodenum and ultimately becomes united with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) the latter receiving the anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) Because of subsidiary vessels and communications there are actually 3 anterior and 2 posterior pancreaticoduodenal arcades The dorsal pancreatic (DP) arises from an accessory middle colic (AcMCol) The latter was distributed to the distal third of the transverse colon one branch communicating with the left colic (LCol) the other with the left branch of the middle colic (MCol) The transverse pancreatic (TP) gives off a slender posterior epiploic branch (PE) to the transverse mesocolon (TrCol) and unites with the a pancreatica magna (PM)

The spleen is supplied by the superior (SP) and the inferior (IP) polar arteries being thus comparable with the kidney The SP arises early from the splenic trunk and in its course to the spleen functions as an accessory left gastric (AcLG) (ramus esophagogastricus posterior ascendens) *In splenectomies it might readily be missed and torn* (W Mayo) The IP arise from the LGE The caudate lobe (CL) is supplied by a branch from the H and a branch from the RH the two being anastomosed CD 2 cm HD 2 cm CBD 8 cm

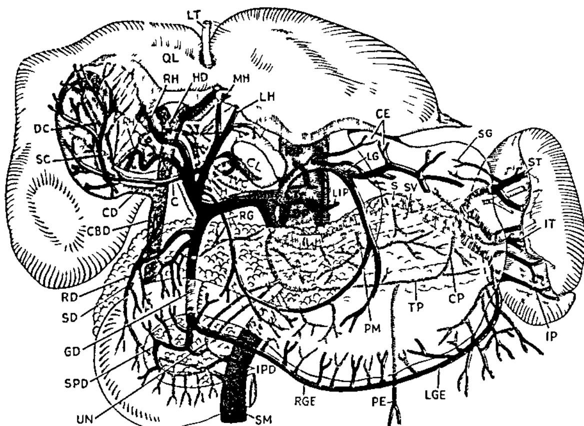


FIG 61 Origin of the cystic artery (C) from the left hepatic (LH) to the left of the hepatic duct (HD) which it crosses anteriorly A celiac trunk (CTr) with 6 branches (M W 69 yrs)

Surgically considered it is *important to know that in approximately 20 per cent of cases (200 bodies) the site of origin of the cystic artery is not located in the cystic triangle of Calot but outside it* Here the entire C arises from the LH and crosses the HD anteriorly as predominantly is the case when the C arises to the left of the HD from the right hepatic (RH) (13%) or from other sources (4%) as from the LH the middle hepatic (MH) or the hepatic (H) When dual cystics are present the superficial (SC) or the deep (DC) cystic or both may arise to the left of the HD

Division of the RH into its probable anterior and posterior segmental branches of the right lobe takes place to the left of the HD *thus placing 2 RH in the cystic triangle* The blood supply to the caudate lobe (CL) follows a common pattern viz a retroportal branch of the RH supplies the caudate process and the right half of the CL proper the left half of the latter receives a branch from the LH Anterior and posterior pancreaticoduodenal arcades made by the retroduodenal (RD) and the superior pancreaticoduodenal (SPD) join the superior mesenteric (SM) via a separate inferior pancreaticoduodenal (IPD) The anterior arcade receives the uncinate branch from the dorsal pancreatic (DP) The DP from the celiac (CTr) (22%) descends behind the splenic vein (SV) and divides into 2 branches—a left branch that becomes the transverse pancreatic (TP) and a right branch that subdivides the upper uncinate branch joining the IPD the lower branch joining the SPD At the distal third of the pancreas the TP unites with the caudal pancreatic (CP) from the splenic (S)

The supraduodenal (SD) from the gastroduodenal (GD) forms a scalloped arcade that is anastomosed with the RD The arcade supplies branches to the first part of the duodenum the pancreas and the common bile duct (CBD) Vascularization of the spleen is accomplished not only by the superior and the inferior terminals (ST IT) of the S but likewise by inferior polar (IP) arteries from the left gastro-epiploic (LGE) 5 of the 13 ultimate lienal branches being derived from this source Note the posterior epiploic branch (PE) of the TP leaving the inferior border of the pancreas to assist in the blood supply of the transverse mesocolon (TrCol)

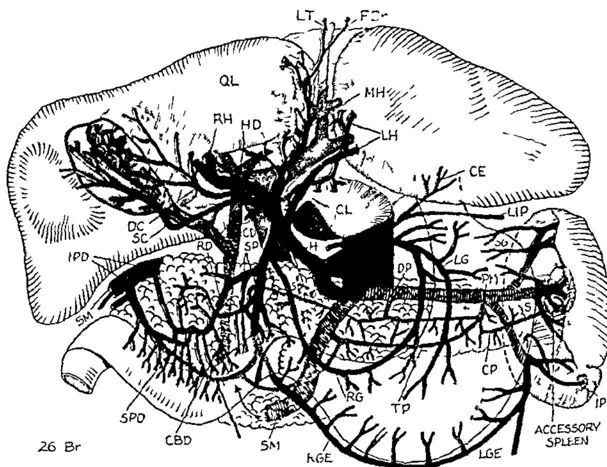


FIG 62 Dual cystic arteries (C) both arising from the right hepatic (RH) to the left of the hepatic duct (HD) where they *criss cross* Complete hepatolienogastric celiac *trunk (CTr) Pea sized accessory spleen* (M N 38 yrs)

The superficial (SC) and the deep (DC) branches of the C (gemellae cysticae of Vesalius) *arise separately* The *SC* crosses the HD and after coursing through the cystic triangle *swerves dorsal to the cystic duct (CD)* to reach the free peritoneal surface of the gallbladder *(GB) The DC after passing* under the SC and anterior to the HD gives twigs to the liver before becoming distributed to the nonperitoneal surface and the GB bed

The duodenum has been turned forward showing the retroduodenal arcade that communicates with the superior mesenteric (SM) via 2 inferior pancreaticoduodenals (IPD) the lower IPD being a common one having received the anterior arcade made by the superior pancreaticoduodenal (SPD) The retroduodenal arcade supplies a branch to the common bile duct *(CBD) a few twigs* to the pancreas and numerous branches to the posterior surface *of the duodenum* There are 2 supraduodenal arteries (SD) one arising *from the gastroduodenal* (GD) the other from the retroduodenal (RD) The transverse pancreatic (TP) arises from the SM, unites with the SPD to the right and with the dorsal pancreatic (DP) and the a pancreatica magna (PM) from the splenic (S) to the left Via the caudal pancreatic (CP) it forms a collateral route to the spleen when the S is ligated proximally

A common site for a pea size accessory spleen (1 cm x 1 cm) is shown vi. in a deep hilar pit A comparable pit is made by the inferior polar artery (IP) from the left gastro-epiploic (LGE) as it sinks into a thumblike lobe of the spleen The right gastric (RG) has a low origin from the GD its most common origin being from the left hepatic (LH) (40%) Cardio-esophageal branches (CE) are given off by the left inferior phrenic (LIP) before it crosses under the esophagus there being no recurrent branch Celiac artery (CTr) *12 mm x 10 mm*

The caudate lobe (CL) is supplied entirely by the LH a branch to the caudate process passing behind the portal vein (PV) Of 26 *hepatic terminals 11 are from the middle* hepatic (MH) Inferior phrenics (LIP) *arise from the aorta by a common stem*

Angular type of union of CD and HD CD 4 cm HD 4 cm CBD 5 cm

Fig 63 A large accessory left gastric (AcLG) from the left hepatic (LH) Odd i e replaced origin of the right hepatic (ReRH) from the celiac artery (CA) which divides distally into the LH and the gastro duodenal (GD) Single cystic (C) anastomosed to the LH (M N 23 yrs)

When a right hepatic (ReRH) arises from the first part of the celiac trunk (CTr) it usually courses *dorsal to the portal vein (PV)* to reach the cystic triangle Here it gives off the dorsal pancreatic (DP) as its first branch Before supplying the C it sends a large branch (most probably the posterior segmental artery) to the fissured area adjacent to the gallbladder (GB) The stem of the C is very short and is anastomosed with the LH via a branch that passes dorsal to the hepatic duct (HD) The upper branch of the ReRH is most probably the anterior segmental branch of the right lobe In addition to the C it gives off a branch that supplies the entire caudate lobe (CL) and unites with the middle hepatic (MH) a branch of the LH Cardio esophageal branches (CE) from the AcLG stemming from the LH unite with CE branches from the left gastric (LG) the short gastrics (SG) and a recurrent branch of the left inferior phrenic (LIP) the latter affording a collateral pathway to the liver when the hepatic (H) and the splenic (S) are ligated The LG arises early from the CTr the right gastric (RG) has late origin from the LH

The duodenum is turned forward to show the retroduodenal (RD) arcade made by the RD Communicating with it are a branch from the DP that swerves around the PV and the common bile duct (CBD) the supra duodenal (SD) which here arises from the ReRH and the superior pancreaticoduodenal (SPD) which joins it via a common inferior pancreaticoduodenal The DP furnishes a transverse pancreatic (TP) to the left a communicating branch to the SPD to the right and a branch that supplies the uncinate process (Un) Two posterior epiploic (omental) branches (PE) from the TP descend to the transverse mesocolon (TrCol) The left gastro-epiploic (LGE) falls short of union with the right gastro epiploic (RGE) (10%)

The cystic duct (CD) opens posteriorly union with the HD being of the angular type CD 2 5 cm HD 3 cm CBD 5 cm

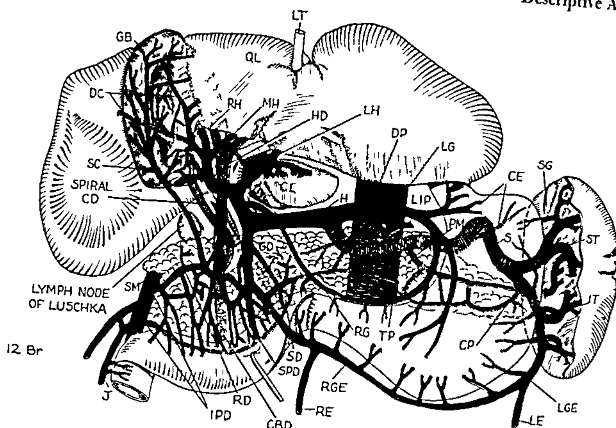


FIG 61 Fairly frequent pattern of the superficial cystic (SC) taking origin from an intestinal artery (RD) and coursing below the cystic duct (CD) The deep cystic (DC) is given off by a branch of the right hepatic (RH) high in the triangle The hepatolienogastric celiac trunk with the very odd origin of the splenic (S) from the common hepatic Spiral type of CD (M W 61 yrs)

The SC may arise *from the retroduodenal (RD) anywhere along the latter's course on the back of the head of the pancreas* As shown here by turning the duodenum forward it arises from the middle of the arcade and on its way to the gallbladder (GB) becomes cryptically concealed for a short stretch by the lymph node of Luschka (LN) or the ganglion of Terrier The posterior pancreaticoduodenal arcade supplies twigs to the intrapancreatic part of the common bile duct (CBD) and the head of the pancreas but large branches to the entire back wall of the duodenum *The arcade should never be rendered entirely dysfunctional in gastric resections or closure of the duodenal stump lest there ensue a stump blow out with fatal results because suture lines give way as a result of lack of regional blood supply*

The anterior arcade made by the superior pancreaticoduodenal (SPD) joins the superior mesenteric (SM) via its own inferior pancreaticoduodenal (IPD) which is anastomosed to a jejunal branch a point to be remembered in duodenojejunal resections The dorsal pancreatic (DP) arises from the celiac The transverse pancreatic (TP) stems from the right gastro epiploic (RGE) and along its course is anastomosed with the DP the a pancreatica magna (PM) and the caudal pancreatic (CP) the latter a branch of the inferior terminal (IT) which here gives rise to the left gastro-epiploic (LGE) Note the *very unusual origin* of the S from the common hepatic only several cases have been observed Celiac 25 mm x 18 mm

The CD spirals about the hepatic duct (HD) posteriorly in a tied condition for 2 cm to open to its left thereby constituting the spiral type of CD CD 6 cm HD 6 cm CBD 6 cm

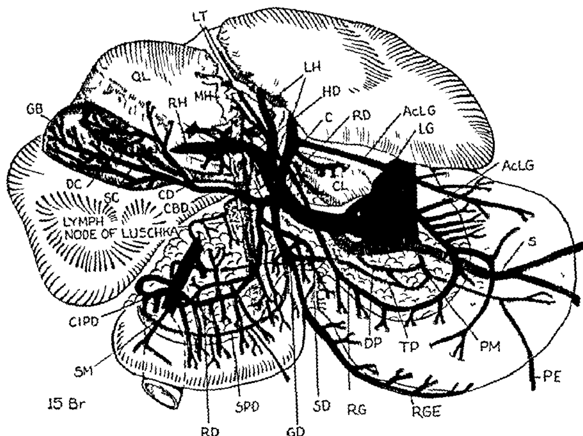


Fig. 65 The entire cystic artery (C) arises from the gastroduodenal (GD) via its retroduodenal (RD) branch. Two accessory left gastrics (AcLG) one from the left hepatic (LH) the other from the splenic (S) (M W 55 yrs)

The C (1 cm long) courses *caudal to the angle formed by the cystic duct (CD) and the common bile duct (CBD) thus reversing the anatomic boundaries of the cystic triangle*. The right hepatic (RH) is plunged into the right lobe without an extrahepatic division. The 2 LH represent an instance in which most probably the inferior and the superior area arteries of the lateral segment of the left lobe arose separately from the hepatic (H). The inferior area artery supplied the middle hepatic (MH) and the right gastric (RG).

The duodenum is turned forward presenting the retroduodenal arcade made by the RD. A posterior branch of the anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) picks up the RD arcade. The 2 arcades join the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD). The supraduodenal (SD) from the RD gives branches to the pancreas the first inch of the duodenum and the pyloric junction. The large AcLG is given off by the LH to the cardio-esophageal end of the stomach. A smaller additional AcLG takes origin from the first part of the S and is distributed to the posterior surface of the stomach as the ramus esophagogastricus posterior ascendens. The transverse pancreatic (TP) from the gastroduodenal (GD) unites with the dorsal pancreatic (DP) and with the a pancreatica magna (PM) from the S. A posterior epiploic (PE) (omental) branch of the TP leaves the inferior surface of the pancreas to become distributed to the left colic flexure.

The caudate lobe (CL) proper is supplied by a branch of the LH the caudate process by a branch from the RH that coursed behind the portal vein (PV). Celiac artery 20 mm x 10 mm. GD 2 cm. HD 2 cm. CBD 8 cm.

Fig 66 A henogastric celiac trunk The right hepatic (ReRH) arises separately from the aorta (A) the left hepatic (ReLH) from the left gastric (LG) hence both are aberrant and of the replaced type Dual cystics both arising in Calot's triangle (M W 68 yrs)

The hepatic trunk after giving off the middle hepatic (MH) to the quadrate lobe (QL) passes *anterior* to the hepatic duct (HD) (12%) as replaced RH It gives off 2 cystics (C) i e superficial (SC) and deep branches (DC) of the C arise separately (*incidence of dual C 25%*) The fissured area under the gallbladder (CB) has branches entering it that may be mistaken for C A large branch of the replaced right hepatic (ReRH) leaves the triangle to supply the caudate lobe (CL) with numerous bifurcating twigs some of which communicate The left lobe of the liver receives its blood supply from the LG via a branch which is not an accessory but a replaced left hepatic (ReLH) it being the only supply for the left lobe

The duodenum has been turned forward to show the posterior pancreaticoduodenal arcade the parent vessel of which is the retroduodenal (RD) The latter gives twigs to the common bile duct (CBD) the head of the pancreas and large branches to all 3 parts of duodenum It unites with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) that has received the anterior arcade made by the superior pancreaticoduodenal (SPD) The dorsal pancreatic (DP) from the splenic (S) (40%) shows its 3 common branches viz the right which joins the SPD the left (transverse pancreatic TP) which joins the S the caudal branch to the uncinate process (Un) of the pancreas The supraduodenal (SD) to the first inch of the duodenum is a branch of the hepatic (H) Tetrahedral spleen with distributed vascularization superior (SP) and inferior (IP) polar arteries short gastrics (SG) and a branch (arteria caudae pancreatis CP) from the left gastro-epiploic (LGE) that unites with the TP and the a pancreatica magna (PM) from the S

Collateral pathways (1) right gastro-epiploic (RGE) and LGE (2) right gastric (RG) and LG (3) SG and cardio-esophageal (CE) branches from the LG (4) ReRH via ReLH and ReLH via MH in umbilical fossa (5) long transverse pancreatic route via DP TP CP and S (6) short transpancreatic route via DP and its right branch that joins the SPD (7) anterior and posterior pancreaticoduodenal arcades (8) arcus epiploicus magnus of Barkow in the great omentum the left limb of the arc being formed by the left epiploic (LE) from the left gastro-epiploic (LGE)

CD 1 cm HD 1 cm CBD 6 cm

FIGURE 66

FIG 67 Incomplete hepatogastric celiac trunk the middle hepatic (MH) stemming from an oddly derived gastroduodenal (GD) the left hepatic (ReLH) from the left gastric (LG) The superior mesenteric (SM) gives rise to the splenic (S) forming a lienomesenteric trunk which gives off the GD Single cystic (C) (M W 77 yrs)

The celiac axis is *oddly split* with resultant diverse origin of the supracolonic vessels The right hepatic (RH) (8 cm) is atypical in its course passing behind the portal vein (PV) Its first branch in Calot s triangle is not the C although it courses *parallel with the cystic duct (CD)* A branch of the RH proceeds to the left under the PV to supply the caudate process and the caudate lobe (CL) The left hepatic (ReLH) arises aberrantly from the LG Reaching the porta hepatis it breaks up into its terminal branches one of which is anastomosed under Glisson s capsule with a branch of the MH another ramus supplies the falciform branches (FBr) The MH the supraduodenal (SD) and the right gastric (RG) arise from a *common trunk* derived from the GD which here aberrantly springs from the SM instead of from the hepatic (H) as usually is the case

The duodenum is turned forward showing a retroduodenal arcade of triple origin being made by 2 retroduodenal arteries (RD) that spring from the RH behind the pancreas and by a branch of the GD The anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) is not anastomosed with the SM but *communicates with the posterior arcade* and the RH behind the PV The transverse pancreatic (TP) from the right gastro-epiploic (RGE) is anastomosed with the dorsal pancreatic (DP) which here is a branch of the RH and with the a pancreatica magna (PM) of the S It gives off 3 posterior epiploic (PE) (omental) branches to the transverse mesocolon (TrCol) The RGE is not anastomosed with the left gastro-epiploic (LGE) (10% incidence) The cardio-esophageal *and* the *fundic regions* of the stomach are supplied by branches from the following sources ReLH recurrent branch of the left inferior phrenic (LIP) the superior polar (SP) and the short gastrics (SG) from the S The CD spirals posteriorly to open just above the RD which may *be injured* during exploration of the common duct (CBD)

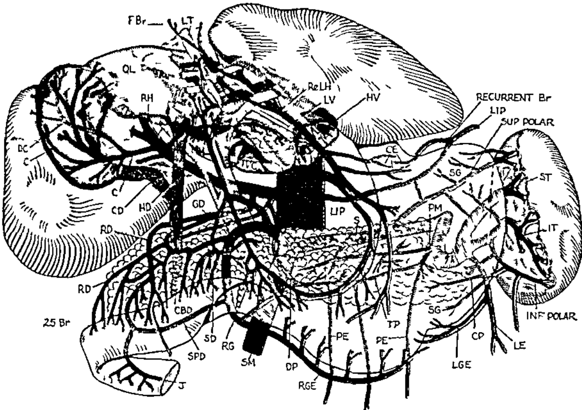

FBr
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RH
ReLH
LV
HV
RECURRENT Br
LIP
SUP POLAR
DC
C
C
CD
HD
GD
IVC
CE
SG
ST
LIP
S
PM
IT
RD
RD
25 Br
CBD
SD
SPD
RG
SM
DP
PE
RGE
TP
PE
SG
CP
LE
LGE
INF POLAR
J

FIGURE 67

Fig 68 Hepatolienogastric celiac trunk (CTr) Separate origin of the left hepatic (LH) from the common hepatic which divides distally into the right hepatic (RH) and the gastroduodenal (GD) Single cystic (C) (F W 77 yrs)

Typical divisional pattern of the RH and the LH As judged from liver casts the LH after supplying the middle hepatic (MH) for the quadrate lobe (QL medial segment of the left lobe) divides into its superior and inferior area branches of the lateral segment of the left lobe The RH divides into an anterior and a posterior segmental branch for the anterior and the posterior segment of the right lobe In the umbilical fossa both the MH and the RH give rise to falciform branches (FBr) which in the *falciform ligament anastomose with branches of the internal mammary, in particular with its ensiform branch* (Haller 1756) The C is a typical textbook kind The caudate lobe (CL) is supplied by a branch of the RH distributed to the caudate process and by a branch of the LH distributed to the CL proper

The anterior pancreaticoduodenal arcade is double being made by 2 superior pancreaticoduodenals (SPD) It communicates with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) with the dorsal pancreatic (DP) and with the transverse pancreatic (TP) which stems from the SPD The posterior pancreaticoduodenal arcade is made by the retroduodenal (RD) which at its commencement gives rise to the supraduodenal (SD) The latter sends branches to the first part of the duodenum the pancreatic tissue and the common bile duct (CBD) The DP to the neck of the pancreas arises from the first part of the splenic (S) It is anastomosed with the TP that supplies the uncinate process (Un) The inferior phrenics (P) have separate origin one arises from the celiac (CTr) the other from the right renal artery (RR) the *latter mode of origin being frequent*

Angular type of union of the cystic duct (CD) with the hepatic duct (HD) CD 3 5 cm HD 4 cm CBD 8 cm

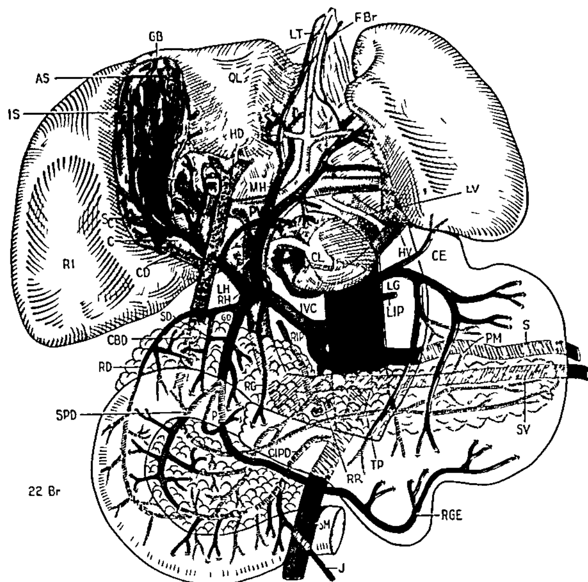

FBr
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MH
PV
LV
SC
C
CL
HV
CE
R1
CD
LG
LH
RH
LIP
IVC
SD
GD
S
CBD
RIP
PM
RD
RG
SPD
P
SV
CIPD
TP
RR
22 Br
RGE
SM
J

FIGURE 68

FIG 69 Split celiac trunk (CTr) the left gastric (LC) arising separately from the aorta (A) the hepatic (H) and the splenic (S) (lienal) forming a hepatolienal trunk Single cystic (C) (M W 43 yrs)

The common hepatic *trifurcates* distally into the gastroduodenal (GD) the right hepatic (RH) and the left hepatic (LH) no hepatic artery proper being formed A typical C divides into its superficial (SC) and deep (DC) branches the gemellae cysticae of Vesalius Before the RH passes under the hepatic duct (HD) it gives off the middle hepatic (MH) for the quadrate lobe (QL) After supplying a falciform branch the LH divides into 2 terminals these most probably being the superior and the inferior area arteries of the lateral segment of the left lobe The caudate lobe (CL) is supplied by 2 branches of the RH that pass dorsal to the portal vein (PV) one goes to the caudate process the other to the CL proper

The anterior and the posterior pancreaticoduodenal arcades are double The retroduodenal (RD) forms 2 arcades on the posterior surface of the head of the pancreas the upper one for the first and the second parts of the duodenum unites directly with the superior mesenteric (SM) via an inferior pancreaticoduodenal (IPD) the lower arcade for the third part of the duodenum unites with 2 posterior branches from the same IPD The superior pancreaticoduodenal (SPD) forms 2 arcades the upper one uniting with a jejunal branch (J)

The supraduodenal (SD) a branch of the RD supplies the upper anterior and the posterior surfaces of the first part of the duodenum the pyloric end of the stomach (along with a pyloric branch of the right gastro epiploic RGE) and the common bile duct (CBD) Since it anastomoses with the SPD it is not an end artery as claimed by Wilkie The dorsal pancreatic (DP) arises from the first part of the H Reaching the junction point of the splenic vein (SV) with the superior mesenteric vein (SMV) at the neck of the pancreas it divides into 2 main branches the one to the left passes anterior to the SV and unites with the transverse pancreatic (TP) that stems from the SPD and communicates with the a pancreatica magna (PM) from the S and the caudal pancreatic (CP) from the left gastro-epiploic (LGE) Another branch of the DP courses dorsal to the PV to unite with the IPD Before doing so it supplies a branch to the first part of the jejunum which receives the upper arcade made by the SPD

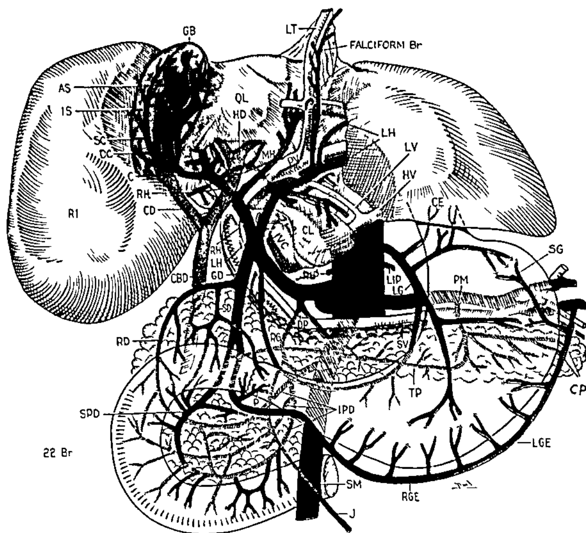

GB
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HD
MH
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HV
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IVC
RH
LH
GD
CBD
LIP
LG
SG
PM
SD
RD
DP
RG
SV
TP
CP
SPD
P
IPD
22 Br
LGE
SM
RGE
J

FIGURE 69

FIG 70 The right hepatic artery (RH) crosses the hepatic duct (HD) anteriorly (12%) instead of passing behind it to reach the cystic triangle Single cystic (C) (M W 81 yrs)

The celiac artery (CTr) unusually long (33 mm) gives rise to 2 left inferior phrenics (LIP) 1 right inferior phrenic (RIP) and the left gastric (LG) *before dividing into the splenic (S) and the hepatic (H)* The left hepatic (LH) divides into its terminal branches these most probably being the superior and the inferior area branches for the lateral segment of the left lobe A ramus of the inferior area branch assists in the blood supply of the quadrate lobe (QL) its major supply coming from the middle hepatic (MH) The RH makes a *caterpillarlike loop in the cystic triangle* and after giving off typical C plunges into the right lobe as a single vessel The caudate lobe (CL) receives its blood supply in 3 regions the caudate process via a branch from the MH the right part of the CL proper via a branch from the MH the left part of the CL proper via a branch from the LH

The anterior pancreaticoduodenal arcade *is double there being 2 superior pancreaticoduodenals* (SPD) one from the gastroduodenal (GD) the other from the right gastro epiploic (RGE) There are 3 posterior arcades, the main arcade being made by the retroduodenal (RD) that joins the superior mesenteric (SM) via a common inferior pancreaticoduodenal (CIPD) The supraduodenal (SD) supplies the first part *of the duodenum the common bile duct* (CBD) and is anastomosed to the right with 2 of the arcades and to the left with the dorsal pancreatic (DP) and the transverse pancreatic (TP) showing that it is not an end artery as claimed by Wilkie The DP arises from the middle colic (MCol) Looping over the splenic vein (SV) it anastomoses with the SD to the right and to the left with the a pancreatica magna (PM) of the S via 2 branches one of which is the TP

Note that the first part of the jejunum receives its blood supply not from the SM directly but from branches given off by the RD arcade In resections in this region this mode of vascularization should always be inspected and the specific jejunal branches (J) saved lest gangrene eventuate in this portion of the small bowel CD 3 5 cm HD 3 5 cm CBD 8 cm

FB
LT
GB
QL
AS
IS
S
D
HD
C
RH
CD
RI
CBD
MH
LH
SD
RG
IVC
CLI
LG
CE
LIP
PM
RIP
DP
GD
SV
TP
P
RD
SPD
SPD
IPD
DP
M COL
J
RGE
SM
34 Br

FIGURE 70

Fig 71 Hepatolienogastric celiac trunk (CTr) A large left inferior phrenic (LIP) derived from the left gastric (LG) supplies part of the left lobe Separate origin of the right gastro epiploic (RGE) from the superior mesenteric (SM) Subvesicular (accessory) hepatic duct (AcHD) Single cystic (C) (M N 65 yrs)

The CTr (20 x 12 mm) gives rise to the common hepatic which after giving off the gastroduodenal (GD) becomes the hepatic artery (H) proper the latter being very short The cystic triangle widened by dissection displays 2 terminal branches of the right hepatic (RH) these most probably being the anterior and the posterior segmental branches of the right lobe A branch of the RH (probably the posterior segmental) to the fissured area may be mistaken for the C The left hepatic (LH) divides into its superior and inferior area branches for the lateral segment of the left lobe and sends a branch to the quadrate lobe (QL) the main supply of which is derived from the middle hepatic (MH) stemming from the RH The entire caudate lobe (CL) is supplied by a branch of the MH

After giving origin to the retroduodenal (RD) and a pyloric branch (P) the GD divides into 2 superior pancreaticoduodenals (SPD) which form 2 anterior pancreaticoduodenal arcades these ending in a common inferior pancreaticoduodenal (IPD) *that here gives origin to the RGE* and a jejunal branch (J) before joining the SM The posterior arcade made by the RD supplies the supraduodenal (SD) and ends in the SM via its own IPD The transverse pancreatic (TP) stems from the upper SPD and communicates with the dorsal pancreatic (DP) a branch of the splenic (S) There are 2 LIP the lower (LIP I) from the aorta (A) supplies a recurrent branch to the esophagus the upper (LIP II) gives a branch to the left lobe this being the only case in 200 in which such a hepatic branch was noted

A subvesicular bile duct (AcHD) traverses the gallbladder (GB) bed Its frequency in 100 vinyl acetate casts of the liver made by Healey and Schroy was 33 per cent Because of its *filamentous character* it may be torn readily in cholecystectomy with resultant leakage of bile and jaundice CD 4 cm HD 4 5 cm CBD 9 cm

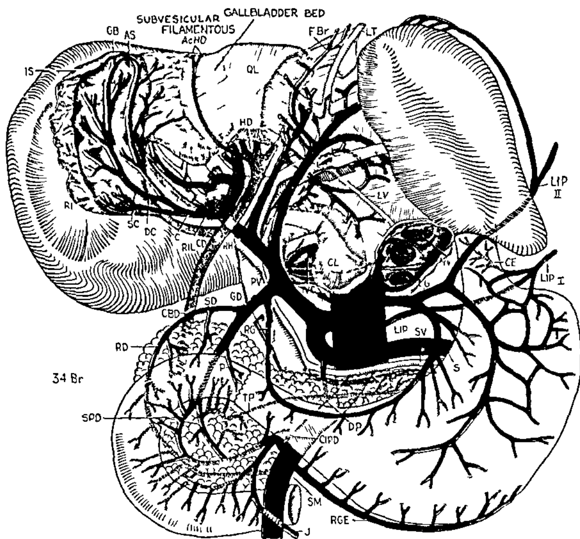

SUBVESICULAR
GALLBLADDER BED
FILAMENTOUS
GB
AS
AcHD
F Br
LT
IS
QL
HD
LIP II
LV
RI
SC
DC
C
RIL
CD
RH
CL
CE
LIP I
PV
IVC
G
SD
GD
CBD
LIP
SV
RG
RD
P
S
34 Br
TP
SPD
DP
CIPD
SM
RGE
J

FIGURE 71

Fig 72 Typical divisional pattern of a hepatohenogastric celiac trunk (CTr) with the left gastric (LG) as its first branch The common hepatic after giving off the gastroduodenal (GD) becomes the hepatic artery (H) *proper which divides into a right hepatic* (RH) and a left hepatic (LH) the latter supplying the middle hepatic (MH) for the quadrate lobe (QL) High single cystic (C) (M N 69 yrs)

The RH divides into 2 major branches which most probably represent the anterior and the posterior segmental branches of the right lobe The C *from an anterior* segmental branch crosses the posterior segmental branch (RIL) After giving off the MH *the* LH divides into the superior and the inferior area branches of the lateral segment of the left lobe the arteries subdividing before entering The superior area branch is anastomosed with the LG via a *small artery it being a remnant of the primitive* vascular arc between the LH and the LG The left part of the caudate lobe (CL) proper is supplied by a branch of the LH *its right portion by a branch of the* RH that likewise supplies the caudate process Both the MH and the LH give off falciform branches to the falciform ligament

The retroduodenal arcade made by the retroduodenal (RD) is single The anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) is double The lower anterior arcade and the *RD arcade unite with the superior mesenteric* (SM) via a common inferior pancreaticoduodenal (IPD) that arises to the left of the SM from a jejunal branch (J) The upper anterior arcade made by a branch of the SPD joins the transverse pancreatic (TP) The TP takes origin from the GD which as here often divides into 3 *branches (the SPD, the right gastro-epiploic RGE the TP)* the pyloric branch (P) being an additive one It communicates with the dorsal pancreatic (DP) and with the a pancreatica magna (PM) of the splenic (S) The supraduodenal (SD) is anastomosed with the GD The cardio-esophageal region of the stomach is supplied by branches from the LG the LIP the SG and from an arc connecting the LG and the LH *The first jejunal branch (J) should be saved in regional resections for it receives the anterior and the posterior pancreaticoduodenal arcades*

The cystic duct (CD) is tied to the hepatic duct (HD) and opens posteriorly CD 1 cm HD 4.5 cm CBD 6 cm

Figure 72

FIG 73 Hepatolienal celiac trunk (CTr) (15 mm × 10 mm) with separate origin of the left gastric (LG) from the aorta (A) The LG stem gives off the inferior phrenics (P) The right hepatic (RH) courses behind the portal vein (PV) Single cystic (C) (M W 65 yrs)

The common hepatic trunk is very short dividing nearly immediately into an RH and a left hepatic (LH) the latter giving rise to the gastroduodenal (GD) The RH courses upward *dorsal to the PV* and upon reaching the cystic triangle gives off a large branch (RIL) that courses in the fissured area below the gallbladder (GB) at a depth of only 1 mm being covered by omental tissue Above this fissure branch courses the C (10 mm × 2 mm) derived from the same posterior segmental branch of the RH Similar in size origin and course the 2 arteries *readily could be confused in a cholecystectomy* The LH after giving off the middle hepatic (MH) for the quadrate lobe (QL) divides into its superior and inferior area branches of the lateral segment of the left lobe the arteries subdividing before entering the liver A ramus of the inferior area branch crosses the umbilical fossa to supply part of the QL and the falciform ligament

The left part of the caudate lobe (CL) proper receives a branch from the superior area branch of the LH its right portion is supplied by a branch of the RH that descends behind the PV this same branch supplies the caudate process by another ramus The anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) ends in an inferior pancreaticoduodenal (IPD) derived from a jejunal branch (J) to the left of the superior mesenteric (SM) *This mode of arcade ending should be looked for in every resection of this region lest by severance of such a jejunal branch (J) vascularization of the duodeno jejunal junction be impaired* The retroduodenal arcade made by the retroduodenal artery (RD) swings upward to end in a branch of the RH which as an IPD descends behind the PV Another branch of the RH descends behind the PV to supply the uncinate process (Un) The dorsal pancreatic (DP) from the splenic (S) is anastomosed to the right with an IPD from the RH to the left it gives off the transverse pancreatic (TP) that unites with the a pancreatica magna (PM) from the S A recurrent branch of the left inferior phrenic (LIP) passes under the esophagus to supply it with cardio-esophageal branches (CE) The cystic duct (CD) opens posteriorly CD 1.5 cm HD 3 cm CBD 7 cm

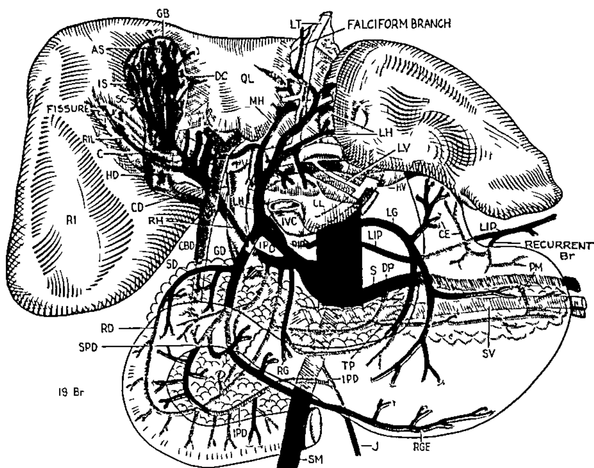

GB
LT
FALCIFORM BRANCH
AS
IS
DC
QL
SC
FISSURE
MH
RIL
LH
C
LV
HD
PV
HV
LH
LL
CD
IVC
LG
RI
RH
LIP
CBD
IPD
RIP
LIP
CE
RECURRENT Br
GD
SD
S
DP
PM
RD
SV
SPD
TP
RG
IPD
19 Br
IPD
J
RGE
SM

FIGURE 73

Fig 74 Hepatolienogastropancreatic celiac trunk (CTr) the 4 arteries (hepatic H splenic S left gastric LG and dorsal pancreatic DP) arising from the same point thereby constituting a tetrapod Three cystic arteries Subvesicular (accessory) *bile duct* (M W 69 yrs)

The right hepatic (RH) divides into its anterior and posterior segmental branches (RIL) the latter coursing in a fissured area below the gallbladder (GB) where its branches are distributed to the side walls of the fissure The anterior segmental branch coursing behind the cystic duct (CD) could have been traumatized in a cholecystectomy

A triple cystic artery (C) actually occurs (only case in 500 bodies) The lower superficial cystic (SC) leaves the cystic triangle *and swerves around the CD The deep* cystic (DC) coursing close to the accessory hepatic duct (AcHD) was concealed cryptically The left hepatic (LH) gives off the middle hepatic (MH) for the medial segment of the left lobe (QL) The caudate lobe (CL) is supplied entirely by a branch of the RH which after passing dorsal to the portal vein (PV) sends branches to the caudate process and the CL proper The subvesicular duct coursing *superficially* in the GB bed could have been torn readily in a removal of the GB causing postoperative leakage of bile

The supraduodenal (SD) forms a wide scalloping arcade with the RD Since its ramifications anastomose with the gastroduodenal (GD), the superior pancreaticoduodenal (SPD) the RD and the transverse pancreatic (TP) it cannot be regarded as an end artery as claimed by Wilkie The anterior pancreaticoduodenal arcade is double the upper loop joins the superior mesenteric (SM) via its own inferior pancreaticoduodenal (IPD) the lower loop unites with the SM via an IPD which also picks up the RD arcade The DP is very large (1 mm) and arises from the tip of the celiac (CTr) thereby rendering the latter a tetrapod (5%) It gives off the TP *to the left and is anastomosed with the* SPD to the right Along its course on the inferior surface of the pancreas the TP gives off a posterior epiploic (PE) branch to the transverse mesocolon (TrCol) Distally it unites with the a pancreatica magna (PM) of the S The left inferior phrenic (LIP) arises from the LG and supplies the cardio esophageal branches (CE) The CD swerves behind the hepatic duct (HD) CD 3 cm HD 3 5 cm CBD 6 cm

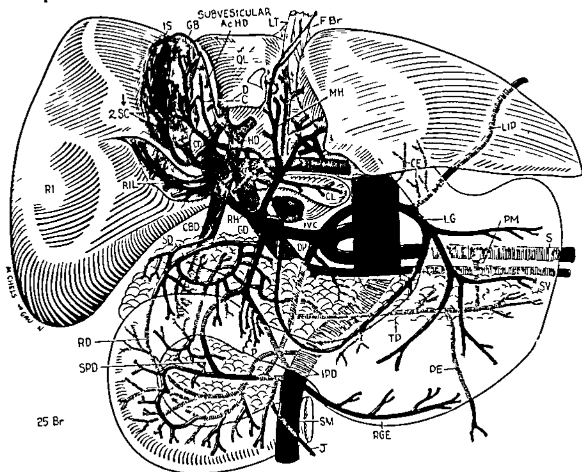

SUBVESICULAR
IS
GB
AcHD
LT
F Br
QL
D
C
MH
2 SC
LIP
CD
HD
CE
RI
RIL
CL
RH
IVC
LG
PM
CBD
GD
SD
DV
S
SV
RD
TD
SPD
P
IPD
DE
25 Br
SM
RGE
J

FIGURE 71

Fig 75 Haller's tripod type of hepato lienogastric celiac trunk (size 15 x 10 mm) The accessory left gastric (AcLG) from the splenic (S) is the ramus esophago gastricus posterior ascendens Anastomosis of the supraduodenal arcade with the right hepatic (RH) Dual cystics (C) (M W adult)

The RH divides into its 2 main branches to the left of the hepatic duct (HD) the branch for the anterior segment of the right lobe coursing *anterior* the branch for the posterior segment coursing *dorsal* to the portal vein (PV) *Hereby the PV is placed in an arterial loop and 2 RH become located in the cystic triangle where they criss cross one another near the junction point of the cystic duct (CD) with the HD* Dual C have nearly contiguous sites of origin The deep cystic (DC) gives liver twigs to the right side of the gallbladder (GB) the superficial (SC) to its left side The left hepatic (LH) divides into its superior and inferior area branches of the lateral segment of the left lobe The middle hepatic (MH) or artery for the medial segment of the left lobe (which includes the quadrate lobe QL) takes origin from the superior area branch

The caudate lobe (CL) is supplied by a branch from the RH and by 2 branches from the LH The SD of Wilkie derived from the RH communicates with the gastroduodenal (GD) the retroduodenal (RD) the superior mesenteric (SM) (via the superior pancreaticoduodenal SPD and the common inferior pancreaticoduodenal IPD) and with the dorsal pancreatic (DP) twice proving it not to be an end artery There are 2 anterior pancreaticoduodenal arcades made by 2 SPD which arise separately from the CD The upper (inner) anterior arcade from the SPD II ends in the S via a DP branch and communicates with the arcade of the SD The lower (outer) anterior arcade from the SPD I ends in the SM via a common IPD and also communicates with the SD The posterior arcade made by the RD is picked up by the posterior branch of the common IPD The dorsal pancreatic (DP) from the S gives off 2 transverse branches one coursing on the ventral the other the transverse pancreatic (TP) on the inferior surface of the pancreas to tie up with the a pancreatica magna (PM) of the S Distally the DP divides into a jejunal branch (J) and into a branch which after supplying the uncinate process (Un) unites with the SPD II Another right branch of the DP unites with the RD The tortuous S supplies an AcLG to the fundic region The GD (6 mm) ends in 4 branches viz 2 SPD the right gastro epiploic (RGE) and a large pyloric branch (P) CD 4 cm HD 5 cm CBD 5 cm

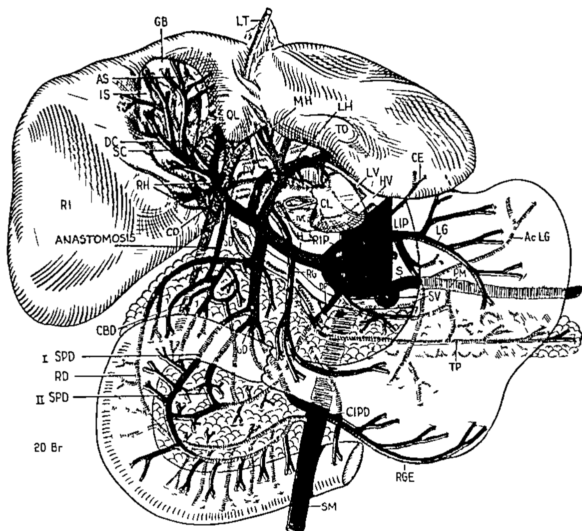

GB
LT
AS
IS
QL
MH
LH
TO
DC
SC
CE
LV
HV
RH
RI
CL
LIP
LG
Ac LG
ANASTOMOSIS
CD
RIP
RG
PM
S
SV
CBD
I SPD
RD
II SPD
TP
CIPD
20 Br
RGE
SM

FIGURE 75

FIG 76 Incomplete hepatolienogastric celiac trunk (CTr) (25 mm x 12 mm) the hepatic artery proper (H) supplying only the right (RH) and the middle (MH) hepatics The left hepatic (ReLH) is replaced from the left gastric (LG) Accessory hepatic duct (AcHD) (F W 65 yrs)

The LG furnishes the *entire blood supply to the left lobe* via a left hepatic which because of its aberrant origin is termed a replaced left hepatic (ReLH) (incidence 12%) Distally the ReLH divides into its superior and inferior area branches for the lateral segment of the left lobe The MH from the RH supplies the medial segment of the left lobe (QL) and sends a ramus to the falciform ligament The RH divides into its anterior and posterior segmental branches for the respective segments of the right lobe The posterior segmental branch (RIL) enters the fissured area giving off short branches before entering the liver The anterior segmental branch gives off the cystic (C) and a branch which descends behind the portal vein (PV) to supply the entire caudate lobe (CL)

The C crosses anterior to a large AcHD which because of its *contiguity with the artery* readily could have been injured in a cholecystectomy causing postoperative leakage of bile The AcHD most probably represents the posterior segmental duct that joined the hepatic duct (HD) *extrahepatically* as warranted by the work of Healey and Schroy Most of the 27 hepatic terminals entering the liver were concerned with the blood supply of the QL and the CL many of them running a subcapsular course

The anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) is double the posterior arcade made by the retroduodenal (RD) is single Both join the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) i e a posterior branch of the IPD picks up the retroduodenal arcade Stemming from the common IPD is a dorsal pancreatic (DP) 5 cm long which picks up the upper anterior arcade To the right it is anastomosed with the transverse pancreatic (TP) which here arises from the SPD to the left it communicates with the splenic (S) twice viz through second DP and through the a pancreatica magna (PM) at the tail of the pancreas Via the 2 DP a collateral route is established between the celiac (CTr) and the SM The esophagus has an abundant blood supply receiving cardio-esophageal branches (CE) from the ReLH the LG and the recurrent branch of the left inferior phrenic (LIP) The cystic duct (CD) opens posteriorly into a biliary tract ampullated at the junction point of the CD CD 3 5 cm HD 4 cm CBD 7 cm

LT
FALCIFORM Br
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QL
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IS
SC
DC
HD
TO
LV
AcHD
RIL
RH
CD
RI
HV
CE
LIP
ReLH
CL
LG
PM
SV
HV
GD
SD
RIP
LIP
S
CBD
DP
RD
27 Br
RG
P
TP
SPD
DP
CIPD
RGE
SM

FIGURE 76

FIG 77 Haller's tripod type of hepatolienogastric celiac trunk (CTr) the 3 main arteries arising at the same point Double cystic artery (C) Subvesicular (accessory) hepatic duct (AcHD) (M W 71 yrs)

The middle hepatic (MH) springs from the proximal end of the gastroduodenal (GD) The right hepatic (RH) divides into its anterior and posterior segmental *branches for the respective segments of the right lobe* As is often the case *each segmental artery of the right lobe gives rise to a C* The superficial cystic (SC) from the posterior segmental artery leaves the triangle and swerves caudad to the cystic duct (CD) to reach the peritoneal surface of the gallbladder (GB) The deep cystic (DC) from the anterior segmental artery crosses the posterior segmental artery anteriorly The left hepatic (LH) supplies the right gastric (RG) and distally divides into its superior and inferior area arteries of the lateral segment of the left lobe The MH from the GD supplies the medial segment of the left lobe (QL) and sends a branch to the falciform ligament The left and the right parts of the caudate lobe (CL) receive branches from the proximal end of *the RH the caudate process from a branch* of the RH that arises distally from its anterior segmental branch and descends behind the portal vein (PV)

An AcHD joins the right branch of the hepatic duct (HD) It is formed by a short duct that emerges from the liver and by a subvesicular duct that courses superficially in the GB bed

Anterior and posterior pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) are single but each arcade joins the superior mesenteric (SM) via its own *inferior pancreaticoduodenal (IPD) In* gastric resections it is important to know that the first part of the jejunum is often supplied by a branch from the IPD (J) An interruption of this supply by severance of this jejunal branch may cause ischemia with subsequent gangrene The supraduodenal (SD) from the RD supplies the common bile duct (CBD) on its way to the first part of the duodenum The transverse pancreatic (TP) stems from the left side of the GD The dorsal pancreatic (DP) *easily located at the junction point of the splenic vein (SV) with the superior mesenteric vein (SMV)* is a branch of the first part of the splenic (S) It supplies the neck of the pancreas and is anastomosed with the TP The posterior branch of the left gastric (LG) anastomoses with the RG but the right *(RGE) and the left* (LGE) gastro-epiploics are not anastomosed (10%) The CD swerves posteriorly to the HD and opens to the left CD 4 5 cm HD 4 5 cm CBD 6 cm

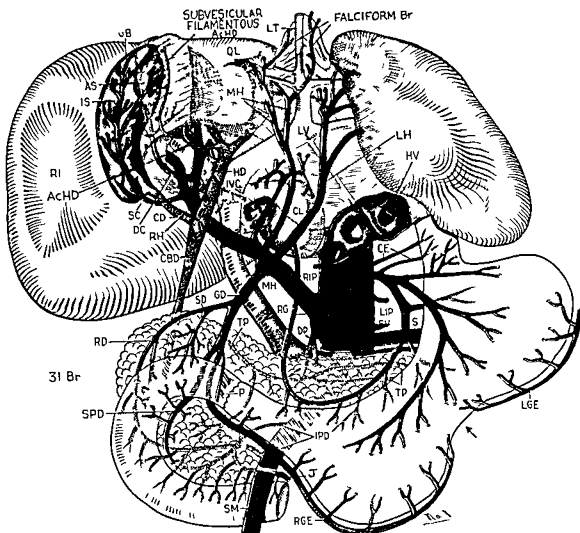

SUBVESICULAR
FILAMENTOUS
AcHD
FALCIFORM Br
LT
GB
QL
AS
IS
MH
LV
LH
HV
RI
AcHD
HD
IVC
CL
SC
CD
DC
RH
CBD
CE
RIP
MH
SD
GD
RG
LIP
S
RD
TP
DP
31 Br
P
TP
LGE
SPD
IPD
J
SM
RGE

FIGURE 77

Fig 77 Haller's tripod type of hepato *lienogastric celiac trunk (CTr) the 3 main* arteries arising at the same point Double cystic artery (C) Subvesicular (accessory) hepatic duct (AcHD) (M W 71 yrs)

The middle hepatic (MH) springs from the proximal end of the gastroduodenal (GD) The right hepatic (RH) divides into its anterior and posterior segmental branches for the respective segments of the right lobe As is often the case *each segmental artery of the right lobe gives rise to a C* The superficial cystic (SC) from the posterior segmental artery leaves the triangle and swerves caudad to the cystic duct (CD) to reach the peritoneal surface of the gallbladder (GB) The deep cystic (DC) from the anterior segmental artery crosses the posterior segmental artery anteriorly The left hepatic (LH) supplies the right gastric (RG) and distally divides *into its* superior and inferior area arteries of the lateral segment of the left lobe The MH from the GD supplies the medial segment *of the left lobe (QL) and sends a branch* to the falciform ligament The left and the right parts of the caudate lobe (CL) receive branches from the proximal end of the RH the caudate process from a branch of the RH that arises distally from its anterior segmental branch and descends behind the portal vein (PV)

An AcHD joins the right branch of the hepatic duct (HD) It is formed by a short *duct that emerges from the liver* and by a subvesicular duct that courses superficially in the GB bed

Anterior and posterior pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) are single but each arcade joins the superior mesenteric (SM) via its own inferior pancreaticoduodenal (IPD) In gastric resections it is important to know that the first part of the jejunum is often supplied by a branch from the IPD (J) An interruption of this supply by severance of this jejunal branch may cause ischemia with subsequent gangrene The supraduodenal (SD) from the RD supplies the common bile duct (CBD) on its way to the first part of the duodenum The transverse pancreatic (TP) stems from the left side of the CD The dorsal pancreatic (DP) *easily located at the junction point of the splenic vein (SV) with the superior mesenteric vein (SMV)* is a branch of the first part of the *splenic (S) It supplies the neck of the pancreas* and is anastomosed with the TP The posterior branch of the left gastric (LG) anastomoses with the RG but the right *(RGE) and the left (LGE) gastro-epiploics* are not anastomosed (10%) The CD swerves posteriorly to the HD and opens to the left CD 4 5 cm HD 4 5 cm CBD 6 cm

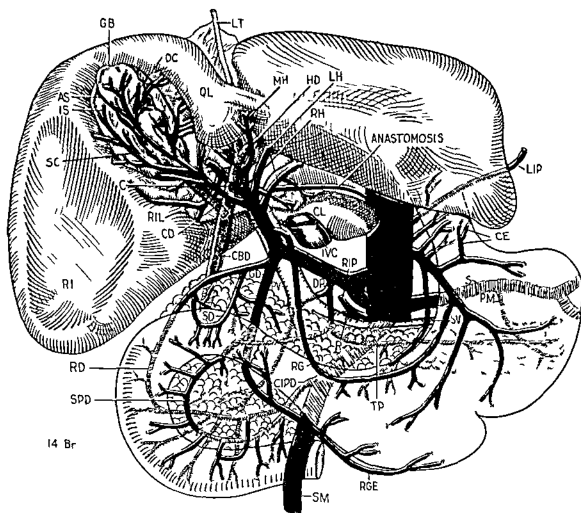

GB
LT
DC
AS
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MH
HD
LH
RH
ANASTOMOSIS
SC
LIP
C
CL
RIL
CD
CE
CBD
IVC
RIP
GD
PV
DP
S
PM
RI
SD
SV
RD
RG
SPD
CIPD
TP
RGE
SM

FIGURE 78

Fig 78 Complete hepatolienogastric celiac trunk (CTr) (30 mm × 10 mm) The right (RH) and the left (LH) hepatics and *the cystic (C) arise from the hepatic artery* proper (H) nearly at the same point the origin of the C being outside Calot's triangle (M W 42 yrs)

The H proper breaks up into 5 main branches Division of the RH into its anterior and posterior segmental branches takes place *to the left of the hepatic duct (HD) thus placing 2 RH in the cystic triangle* The posterior segmental branch (RIL) of *the RH courses behind the C which previously* crossed the HD anteriorly The HD is thus placed in an arterial circle and readily could have been traumatized in a cholecystectomy with resultant obstruction of the common duct The 2 LH shown most probably represent the superior and the inferior area arteries of the lateral segment of the left lobe The superior LH branch is anastomosed with the LG via a *small artery this being a remnant of a* primitive embryonic connection between the 2 vessels (Piquand) By this channel blood may be routed from the LG to the liver when the common hepatic or the hepatic proper artery is ligated Branches from the LH supply the entire caudate lobe (CL) one branch going to the caudate process the other to the CL proper

The anterior and the posterior pancreaticoduodenal arcades made by the retroduodenal (RD) and the superior pancreaticoduodenal (SPD) unite with the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) and supply numerous branches to the front and the back of all 3 portions of the duodenum The supraduodenal (SD) forms a scalloped arcade with the RD from which branches are distributed to the first part of the duodenum the common bile duct (CBD) and the pancreas The dorsal pancreatic (DP) *shows its typical 3 branches to the left* the transverse pancreatic (TP) which at tail of the pancreas anastomoses with the a pancreatica magna (PM) of the splenic (S) 2 right branches of which one (the lower) passes behind the superior mesenteric vein (SMV) to unite with the SPD and the other (the upper) passes behind the portal vein (PV) to become distributed to the uncinate process (Un) The left inferior phrenic (LIP) *supplies* branches to the posterior surface of the esophagus The right inferior phrenic (RIP) arises from the right renal artery (RR) as commonly is the case The LG anastomoses with the right gastric (RG) via its anterior branch The cystic duct (CD) opens posterolaterally union with the HD being of the angular type CD 3 5 cm HD 3 5 cm CBD 6 5 cm

FIGURE 78

FIG 79 Complete hepatolienal celiac trunk (CTr) with left gastric (LG) as the first branch Two left inferior phrenics (LIP) one derived from the celiac (CTr) the other from the left hepatic (LH) Origin of the cystic (C) from the right hepatic (RH) to the left of the hepatic duct (HD) (M N adult)

The common hepatic *trifurcates* into the gastroduodenal (GD) the RH and the LH The C crosses anterior to the HD as it nearly invariably does when it arises to the left of the HD i e outside the triangle of Calot from a RH a middle hepatic (MH) or a LH The C divides into its superficial (SC) and deep (DC) branches—the gemellae cysticae of Vesalius—these being anastomosed distally

The LH is anastomosed with the LG via a large arterial arc from which arises *a large accessory LIP* Another LIP arises from the CTr and via its recurrent branch supplies cardio-esophageal branches (CE) The LH sends a branch across the umbilical fossa under the ligamentum teres (LT) as a regional supply to the quadrate lobe (QL) the main supply of which comes from the MH The caudate lobe (CL) receives its blood supply in 3 different regions the left and the right parts of the CL proper from the LH and the RH the caudate process from the RH This pattern of vascularization is a prevailing one as seen in the casts of Healey and Schroy

Large anastomosis exists between the RH and the retroduodenal (RD) Had the common hepatic been ligated it would have afforded an effective collateral pathway to the liver via the common inferior pancreaticoduodenal (CIPD) from the superior mesenteric (SM) There are 2 superior pancreaticoduodenals (SPD) one stemming from the GD the other from the right gastro epiploic (RGE) They form 2 anterior pancreaticoduodenal arcades which become united with the posterior arcade (made by the RD) via a common IPD The supraduodenal (SD) arises from the RD the transverse pancreatic (TP) from the GD the dorsal pancreatic (DP) from the splenic (S) Note the absence of anastomosis between the RGE and the left gastro-epiploic (LGE) Since this condition occurs with an incidence of 10% *the infra gastric arterial arc should be investigated in every gastric resection lest by taking the LGE vascularization of greater curvature be impaired* Note likewise the large vein coming to the surface in the gallbladder bed Inattentive manipulation of it could cause profuse and annoying hemorrhage CD 3 cm HD 3 cm CBD 8 cm

Figure 79

Fig 80 A tetrapod celiac artery (size 20 mm × 12 mm) with the hepatic (H) the left gastric (LG) the splenic (S) and *the dorsal pancreatic (DP) arising from the same point (5%)* ***Transposed umbilical fossa*** **with the ligamentum teres (LT) coursing to the left of the gallbladder (GB) (only case in 500 bodies)** *Dual cystic arteries (C)* (M N adult)

The anatomy of the hepatic pedicle is *extremely complicated and surgically considered would have presented hazards as regards both arteries and ducts* The hepatic artery proper divides to the left of the hepatic duct (HD) into its anterior and posterior segmental branches The posterior segmental branch crosses ventral to the HD and the cystic duct (CD) and gives off the superficial cystic (SC) The anterior segmental branch courses dorsal to the HD and its right branch and in the cystic triangle gives off the middle hepatic (MH) and the deep cystic (DC) The celiac left hepatic (LH) is small and most probably represents the inferior area branch of the lateral segment of the left lobe for there in another left hepatic (AcLH 5 mm wide) from the LG to supply the superior area of the lateral segment *A branch of the* MH descends behind the portal vein (PV) *to supply the caudate lobe (CL)*

The posterior pancreaticoduodenal arcade made by the retroduodenal (RD) becomes united with the anterior arcade which begins with the superior pancreaticoduodenal (SPD) *Both PD* arcades join the superior mesenteric (SM) via a common inferior pancreaticoduodenal (CIPD) from which a large jejunal branch (J) is given off The DP descends behind the splenic vein (SV) and gives off 2 transverse pancreatics (TP) to the left and a branch to the right that joins the SPD Near its origin from the CA the DP supplies a branch to the uncinate process (Un) this branch passing behind the superior mesenteric vein (SMV) The TP emits a branch from the inferior surface of the pancreas to the transverse mesocolon (TrCol) An unnamed branch of the gastroduodenal (GD) courses along the ventral surface of the pancreas being superficial The supraduodenal (SD) and the RD supply the common bile duct (CBD)

The CD represents the long parallel type It was 7 cm long before opening *into the* CBD For 4 cm it was intimately associated with the HD *running one half of this* length parallel with it and one half poste*rior to it Such long parallel* CD may harbor residual gallstones CD 7 cm HD 7 *cm* CBD 3 5 *cm* there being little left of its supraduodenal part

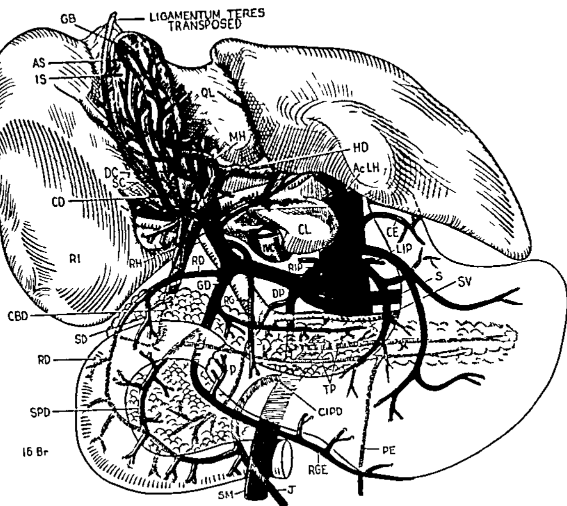

GB
LIGAMENTUM TERES
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MH
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Ac LH
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CE
LIP
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RH
RD
RIP
S
SV
GD
RG
DP
CBD
SD
RD
P
TP
CIPD
SPD
16 Br
PE
RGE
SM
J

FIGURE 80

FIG 81 Hepatolienogastric celiac trunk (CTr) (20 mm x 12 mm) with left gastric (LG) as its first branch Odd type of supraduodenal artery of Wilkie (SD) Right hepatic (RH) ventral to the hepatic duct (HD) Two ventral and 2 dorsal pancreaticoduodenal arcades (M W adult)

The common hepatic *trifurcates* into the gastroduodenal (GD) the RH and the left hepatic (LH) The RH as it crosses the HD ventrally (12%) gives off the cystic (C) which divides into a superficial (SC) and a deep branch (DC) The SC *swerves around the cystic duct (CD)* to reach the free peritoneal surface the DC gives rise to a fairly large liver branch before supplying the attached surface of the gallbladder (GB) A branch of the RH probably the posterior segmental branch (RIL) crosses the C dorsally and surgically considered would be subject to harm in a cholecystectomy The LH after supplying the middle hepatic (MH) for the quadrate lobe (QL) divides into its superior and inferior area arteries of the lateral segment of the left lobe both subdividing before entering The caudate lobe (CL) is supplied by a branch of the RH that passed behind the portal vein (PV)

The SD is very odd and vascularizes an extensive area Stemming from the GD it crosses the common bile duct (CBD) anteriorly gives branches to it and to the first part of the duodenum then swings posteriorly to form an arcade from which the first part of the duodenum is supplied in the back Through its ramifications the SD is anastomosed with the GD the dorsal pancreatic (DP) and the retroduodenal (RD) and therefore is not an end artery

The main retroduodenal arcade is made by the RD which here is a branch of the DP that passes behind the splenic (S) and *the superior mesenteric vein (SMV)* supplying in its course a branch to the uncinate process (Un) The anterior pancreaticoduodenal arcade is double an upper branch of the superior pancreaticoduodenal (SPD) forms the subsidiary anterior arcade and gives rise to the transverse pancreatic (TP) The primary anterior and posterior arcades unite with the superior mesenteric (SM) via a large common inferior pancreaticoduodenal (CIPD) that arises from the superior mesenteric (SM) (4 cm from the latter s commencement) and *which gives off a very large jejunal branch (J) to a critically vascularized duodenojejunal junction* The TP arises from the SPD the DP from the S Anastomosis between the right gastric (RG) and the LG is effected behind the lesser curvature of the stomach The CD is tied to the HD for a short stretch CD 5 cm HD 4 5 cm CBD 5 cm

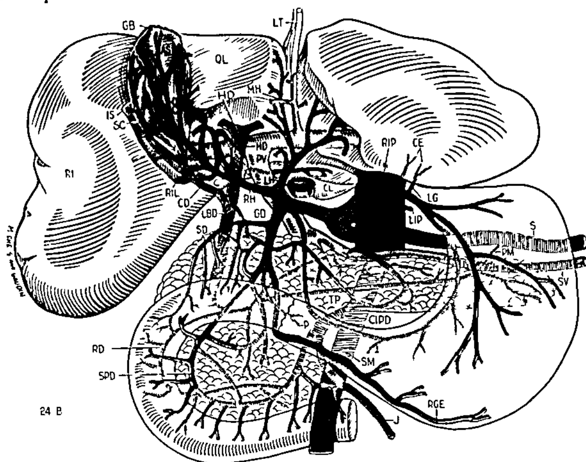

GB
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SC
RIP
CE
HD
PV
LH
R1
RIL
C
CL
LG
CD
RH
LBD
GD
LIP
SD
S
PM
SV
TP
P
CIPD
RD
SM
SPD
RGE
24 B
J

FIGURE 81

Fig. 82. Separate origin of the right hepatic (ReRH) *from the superior mesenteric* (SM) is the incomplete hepatolienogastric *trunk (CTr) divides into the left hepatic* (LH) and the gastroduodenal (GD). Dual cystic arteries (C), the superficial (SC) being anastomosed with the LH. (M. N. 73 yrs.)

Shortly (1 cm.) after its origin from the aorta (A) the SM gives off the right hepatic (ReRH) for the right lobe. In its course behind the portal vein (PV) and the head of the pancreas the ReRH gives off 2 branches that serve as the inferior pancreaticoduodenals (IPD) for the anterior and the posterior pancreaticoduodenal arcades. Farther on it gives rise to the retroduodenal (RD). Reaching the cystic triangle it divides into its anterior and posterior segmental branches but before doing so gives off the C. The stem of the C is very short, so much so that *its superficial and deep branches appear to arise from same point. The SC is anastomosed with the LH by a vessel that runs parallel with the cystic duct (CD)*, crosses the hepatic duct (HD) anteriorly and furnishes the blood supply to the caudate lobe (CL). The anatomic arrangement of the vessels shows the surgical hazards to which the *common hepatic duct* may be exposed when looking for the C. The LH gives off the middle hepatic (MH), then divides into its superior and inferior area branches for the lateral segment of the left lobe.

The anterior and the posterior pancre*aticoduodenal arcades* are double and are anastomosed with vessels derived from the *celiac (CTr)* and the *SM*. The dual posterior arcades are made by the RD, which here springs from the ReRH, and by the supraduodenal (SD), a branch of the RD. They end via 2 IPD given off by the ReRH *behind the pancreas*. Dual anterior arcades are made by the superior pancreaticoduodenal (SPD): the upper arcade unites with the dorsal pancreatic (DP) from the CA, the lower arcade unites with the ReRH via an IPD partly shared by the posterior arcade. *In pancreaticoduodenal resections the site of origin of the IPD should always be checked, for one or two of them may arise from a ReRH behind the pancreas.* After passing under the splenic (S) the DP ties up with the transverse *pancreatic (TP)*, a branch of the SPD. The left inferior phrenic (LIP) supplies a *recurrent branch to the esophagus* which is extensively anastomosed with cardio-esophageal branches *(CE) from the* left gastric (LG) and the short gastrics (SG) of the splenic (S). *As often is the case (10%)* there was no large arterial connection between the right *(RGE) and the left (LGE)* gastro-epiploics.

The CD opens anteriorly *and is of the* angular type. CD 3 cm., HD 3 cm., CBD 7 cm.

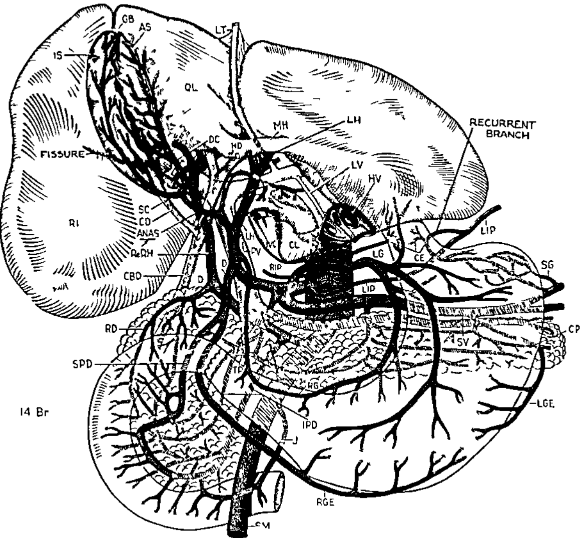

GB
AS
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LT
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MH
LH
RECURRENT BRANCH
FISSURE
DC
HD
LV
HV
SC
CD
ANAS
ReRH
CBD
RL
LH
PV
IVC
CL
LIP
LG
CE
SG
RIP
D
LID
RD
CP
SV
SPD
TP
RG
LGE
14 Br
IPD
J
RGE
SM

Figure 82

FIG 83 Aberrant origin of both the right (ReRH) and left (ReLH) hepatics the celiac hepatic dividing distally only into the middle hepatic (MH) and the gastroduodenal (GD) Large accessory left gastric (AcLG) from the replaced left hepatic (ReLH) Single cystic (C) A gastrojejunostomy had been performed (M N 43 yrs)

A right hepatic (ReRH 6 mm wide 7 cm long) arises separately from the first part of the celiac (CTr) (23 mm x 6 mm) and takes a course comparable with that taken by a RH arising from the superior mesenteric (SM) i e it passes dorsal to the portal vein (PV) After giving off a typical C (15 mm long 2 mm wide) it divides into its anterior and posterior segmental branches the arched vessel (RH) most probably pertaining to the posterior segment of the right lobe The MH (4 mm wide) for the quadrate lobe (QL) arises in conjunction with the GD from the celiac hepatic trunk A branch of the MH is anastomosed with the caudate lobe (CL) artery which stems from the ReRH The LH (ReLH 5 mm wide) from the LC gives off 2 large AcLG to the cardio-esophageal and the fundic regions of the stomach where they unite with the cardioesophageal branches (CE) from the left inferior phrenics (LIP) and the short gastrics (SG) Distally the ReLH divides into its superior and inferior area branches for the lateral segment of the left lobe Its branch to the falciform ligament is comparable with that coming from the MH *These falciform branches may anastomose with the end branches of the internal mammary* (especially with the ensiform branch of Haller 1756) and when the hepatic artery (H) is ligated they could effect an arterial collateral pathway by bringing a backflow of blood to the liver via the MH and the LH with which they are connected from vessels above the diaphragm

The anterior and the posterior pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) join the SM via a common inferior pancreaticoduodenal (CIPD) The dorsal pancreatic (DP) from the SM gives off the transverse pancreatic (TP) to the left and to the right sends a branch that unites with the SPD At the tail end of the pancreas the TP unites with the a pancreatica magna (PM) from the splenic (S) and the caudal pancreatic (CP) from the left gastro-epiploic (LGE) The right inferior phrenic (RIP) arises from the right renal (RR) and supplies a suprarenal branch The supraduodenal (SD) from the RD supplies the common bile duct (CBD) and the anterior and the posterior surfaces of the first inch of the duodenum along with a branch of the GD

Note the vascularization changes which took place after a *gastrojejunostomy* had been performed Jejunal branches (J) from the SM became enlarged and a branch of the DP grew out to vascularize the sutured area

Cystic duct (CD) (20 mm x 4 mm) opened in the hepatic duct (HD) posteriorly CD 2 cm HD 4 cm CBD 8 cm

FIGURE 83

Fig 81 The celiac hepatic divides into a *left (LH)* and a *middle (MH)* hepatic leaving the right hepatic (ReRH) to arise i e be replaced by the superior mesenteric (SM) Incomplete hepatolienogastric celiac trunk which here is bulged and constricted Maximal number (65) of terminal hepatics (M W 57 yrs)

The celiac artery is oddly bulged in its center and *constricted at its root the latter condition being due to impingement of the crura of the diaphragm* The LH divides into its superior and inferior area branches of the lateral segment of the left lobe The ReRH from the SM in its ascent to the cystic triangle (widened by dissection) crosses the junction point of the cystic duct (CD) with the hepatic duct (HD) and divides into an anterior and a posterior segmental branch which become subdivided before entering the right lobe The cystic artery (C) from the anterior segmental division of the ReRH is very large its deep branch (DC) being more a liver artery than a cystic Inattentive severance of such a deep cystic (DC) would result in annoying bleeding

An amazingly high number of terminal hepatics are present The anterior segmental branch of the ReRH supplied 10 the posterior segmental branch 11 the LH 12 and the MH 22 making a total of 65 *the highest number* ever encountered Most hepatic terminals run a subcapsular course in the umbilical fossa and the porta hepatis and were exposed when Glisson s capsule was removed *The extent and the depths of the liver parenchyme vascularized by the subcapsular branches remains a major unsolved problem* The right and the left parts of the caudate lobe proper (CL) are supplied by the MH the caudate process by the replaced right hepatic (ReRH) via 2 rami of its posterior segmental branch

The retroduodenal (RD) here is derived from the ReRH It is anastomosed with the gastroduodenal (GD) via the supraduodenal (SD) that makes a loop around the common bile duct (CBD) supplying it with twigs The anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) picks up the RD arcade by a posterior branch Both arcades end in an inferior pancreaticoduodenal (CIPD) which instead of being derived from the SM takes origin from the ReRH which gives off a large jejunal branch (J) The dorsal pancreatic (DP) is double One supplies the uncinate process (Un) the other unites with the transverse pancreatic (TP) from the right gastro epiploic (RGE) that courses parallel with the pancreatic duct (PD) and *is anastomosed with the a pancreatica magna* (PM) of the splenic (S) and the caudal pancreatic (CP) of the left gastro-epiploic (LGE) The cystic duct (CD) swerves posterior to the HD and accompanies it for a stretch before opening CD 6 cm HD 6 cm CBD 5 cm

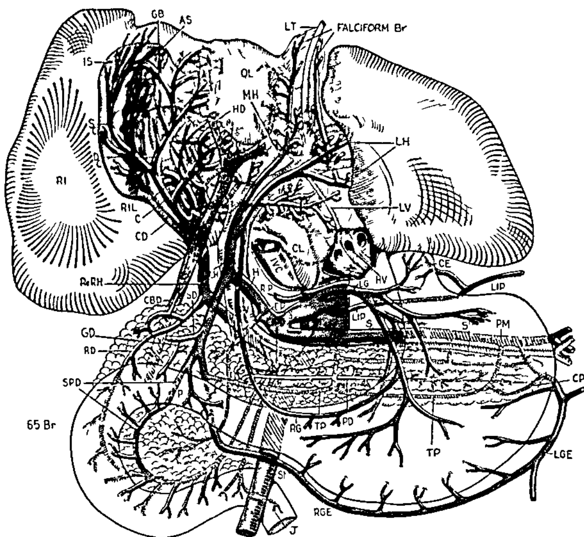

GB
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C
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IVC
CE
RrRH
HV
LG
LIP
CBD
SD
RP
LIP
S
S
PM
GD
RD
SPD
P
CP
65 Br
RG
TP
PD
TP
LGE
ST
RGE
J

FIGURE 81

Fig. 81. The celiac hepatic divides into a left (LH) and a middle (MH) hepatic, leaving the right hepatic (ReRH) to arise, i.e., be replaced by the superior mesenteric (SM). Incomplete hepatolienogastric celiac trunk which here is bulged and constricted. Maximal number (65) of terminal hepatics. (M. W., 57 yrs.)

The celiac artery is oddly bulged in its center and *constricted at its root, the latter condition being due to impingement of the crura of the diaphragm.* The LH divides into its superior and inferior area branches of the lateral segment of the left lobe. The ReRH from the SM in its ascent to the cystic triangle (widened by dissection) *crosses the junction point of the cystic* duct (CD) with the hepatic duct (HD) and divides into an anterior and a posterior segmental branch which become subdivided before entering the right lobe. The cystic artery (C) from the anterior segmental division of the ReRH is very large, its deep branch (DC) being more a liver artery than a cystic. Inattentive severance of such a deep cystic (DC) would result in annoying bleeding.

An amazingly high number of terminal hepatics are present. The anterior segmental branch of the ReRH supplied 10, the posterior segmental branch 11, the LH 12, and the MH 22, making a total of 65, *the highest number* ever encountered. Most hepatic terminals run a subcapsular course in the umbilical fossa and the porta hepatis and were exposed when Glisson's capsule was removed. *The extent and the depths of the liver parenchyme vascularized by the subcapsular branches remains a major unsolved problem.* The right and the left parts of the caudate lobe proper (CL) are supplied by the MH, the caudate process by the replaced right hepatic (ReRH) via 2 rami of its posterior segmental branch.

The retroduodenal (RD) here is derived from the ReRH. It is anastomosed with the gastroduodenal (GD) via the supraduodenal (SD) that makes a loop around the common bile duct (CBD) supplying it with twigs. The anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) picks up *the RD arcade by a* posterior branch. Both arcades end in an inferior pancreaticoduodenal (CIPD) which, instead of being derived from the SM, takes origin from the ReRH which gives off a large jejunal branch (J). The dorsal pancreatic (DP) is double. One supplies the uncinate process (Un), the other unites with the transverse pancreatic (TP) from the right gastroepiploic (RGE) that courses parallel with the pancreatic duct (PD) and is anastomosed with the a. pancreatica magna (PM) of the splenic (S) and the caudal pancreatic (CP) of the left gastro-epiploic (LGE). The cystic duct (CD) swerves posterior to the HD and accompanies it for a stretch before opening. CD, 6 cm.; HD, 6 cm.; CBD, 5 cm.

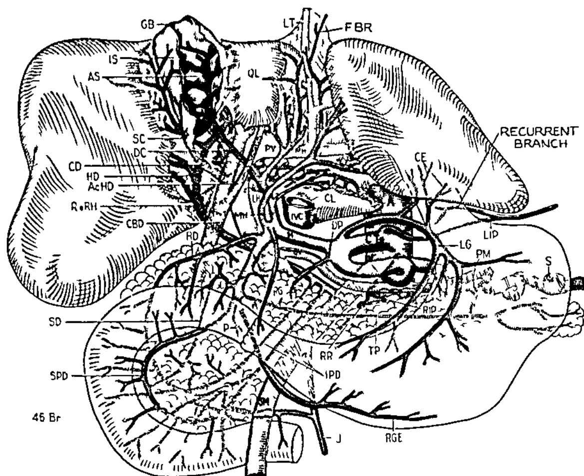

GB
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RECURRENT BRANCH
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AcHD
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IVC
R.RH
CBD
DP
LIP
RD
LG
PM
S
RG
RIP
SD
P
TP
RR
SPD
IPD
SM
46 Br
J
RGE

FIGURE 85

FIG 85 Very odd and exceptional course taken by the deep cystic artery (DC) which after its origin from the middle hepatic (MH) passes dorsal to a left accessory hepatic duct (AcHD) and ventral to the hepatic duct (HD) Superficial cystic (SC) from a replaced right hepatic (ReRH) 46 hepatic terminals (M W 66 yrs)

The common hepatic ends by giving off at the same point the gastroduodenal (GD) the right gastric (RG) the MH and the left hepatic (LH) no hepatic artery proper (H) being present The origin of the right hepatic (ReRH 8 cm long) was shifted to the superior mesenteric (SM) Extrahepatically it gave rise to (1) 2 inferior pancreaticoduodenals (IPD) these being end vessels of the anterior and the posterior pancreaticoduodenal arcades (2) 3 liver branches to the fissured area below the gallbladder (GB) these most probably being for the posterior segment of the right lobe (3) the SC which leaves Calot s triangle to reach the peritoneal surface of the GB (4) the caudate lobe (CL) artery which descends behind the portal vein (PV) (5) the anterior segmental branch for the anterior segment of the right lobe Severance of such a ReRH in a cholecystectomy would be disastrous leaving a large section of liver without a blood supply

Equally precarious surgically considered is the DC given off by the MH It ran a course of 5 cm before reaching the GB Manipulation of it beyond the contours of the GB might have resulted in severe injury not only to the HD but likewise to a large AcHD (30 mm × 4 mm) under which it passed *Formation of the left AcHD was due to the fact that one of the main segmental ducts of the left lobe (probably that of the quadrate lobe, QL) failed to join the left branch of the HD inside the liver ending instead in the common bile duct (CBD) a bit below the junction point of the cystic duct (CD)* At the Centennial Convention of the A M A at Atlantic City (1947) this demonstrated specimen was *the most startling and unbelievable one for grossly it appeared that the DC from the MH passed through the HD* The LH divides into its superior and inferior area branches of the lateral segment of the left lobe The CL is supplied by a branch from the MH and the ReRH

The two pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) end in 2 IPD which here are given off by the ReRH instead of arising from the SM The supraduodenal (SD) joins the SPD The transverse pancreatic (TP) (3 mm wide) stems from the GD and unites with the a pancreatica magna (PM) of the tortuous splenic (S) The right inferior phrenic (RIP) arises from the right renal (RR) The CD opens into the HD at a point higher than the opening for the left AcHD which joins the CBD CD 4 cm HD 1 cm CBD 8 cm

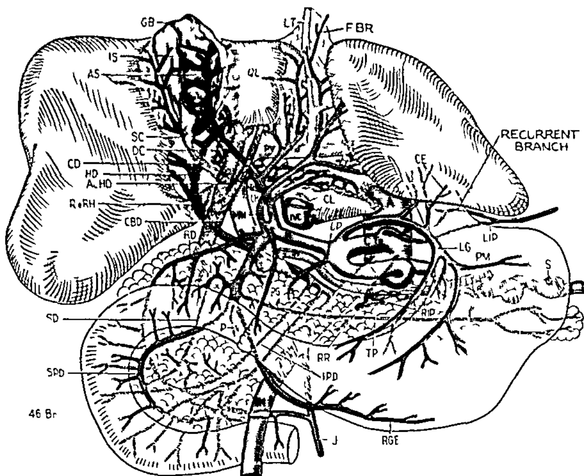

GB
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A.HD
R.RH
CBD
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SPD
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FBR
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RECURRENT BRANCH
CE
CL
NC
LD
LID
LG
PM
S
RIP
PS
P
RR
TP
IPD
J
RGE

FIGURE 85

Fig 86 Three celiac hepatics from a complete heptohenogastric celiac trunk (CTr) (18 mm × 7 mm) plus an accessory right hepatic (AcRH) from the superior mesenteric (SM) and an accessory left hepatic (AcLH) from the left gastric (LG)—hence 5 major liver arteries Large accessory hepatic duct (AcHD) which joined the cystic duct (CD) Single cystic artery (C) (M N 59 yrs)

The blood supply to the liver came from 3 sources to wit the celiac (CTr) the LG and the SM The common hepatic (H 35 mm long) after giving off the gastroduodenal (GD) became the hepatic artery proper which broke up into the left (LH) the middle (MH) and the right (RH) hepatics and the C The celiac LH most probably supplied the inferior area of the lateral segment of the left lobe while the AcLH from the LG furnished the blood supply to the superior area of the lateral segment and in addition gave off an accessory left gastric (AcLG) The MH shows 3 branches these most probably being area branches of the medial segment of the left lobe The celiac RH passes under the AcHD Judged from casts it most probably represents the anterior segmental branch of the right lobe for there is another RH (AcRH) from the SM that supplies the posterior segment

The large AcHD joins the CD shortly before the latter opens into the hepatic duct (HD) Judged from casts made by Healey and Schroy the AcHD represents a major segmental duct that failed to become united with the right branch of the HD inside the liver *Note the hazardous condition of the site of origin and the course of the C* Arising from the RH to the left of the HD it crosses the HD and the AcHD ventrally before dividing into its superficial (SC) and deep (DC) branches The C was 3 cm long

The caudate lobe was supplied by the RH via branches which gave off rami to the caudate process and the right and the left parts of the caudate lobe (CL) proper The anterior and the posterior pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) became united with the SM via a common inferior pancreaticoduodenal (CIPD) A subsidiary anterior arcade joins the dorsal pancreatic (DP) *which here oddly arises from the AcRH behind the pancreas* The transverse pancreatic (TP) stems from the SPD communicates with the DP at the isthmus (neck) of the pancreas and with the a pancreatica magna (PM) of the splenic (S) and the caudal pancreatic (CP) of the left gastro epiploic (LGE) at the tail of the pancreas The right gastric (RG) has a low origin i e stems from the GD The LG gives off an AcLG from which arises a large AcLG and a shorter cardio esophageal (CE) branch both anastomosing with CE branches of the recurrent branch of the left inferior phrenic (LIP) There are 2 right inferior phrenics (RIP) one from the aorta (A) the other from the right renal (R) CD 3 5 cm HD 4 cm CBD 7 cm

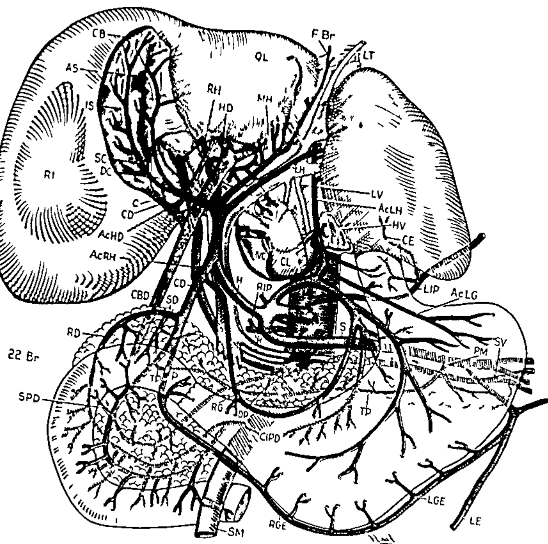

CB
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SC
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C
CD
AcHD
AcRH
CBD
SD
CD
RD
22 Br
SPD
TD
P
RG
DP
CIPD
F Br
LT
QL
RH
HD
MH
LH
LV
AcLH
HV
CE
VC
CL
H
RIP
S
LIP
AcLG
SV
PM
TD
LGE
LE
RGE
SM

FIGURE 86

FIG 87 Early origin of the hepatic branches to the medial segment (quadrate lobe QL) and the lateral segment of the left lobe this being accomplished by 2 middle (MH) and 2 left (LH) hepatics Single cystic (C) from an AcRH derived from the superior mesenteric (SM) 32 hepatic terminals (M N 58 yrs)

The celiac hepatic gives off the gastroduodenal (GD) 2 LH the right hepatic (RH) and the right gastric (RG) nearly at the same point The 2 LH proceed to the lateral segment of the left lobe to supply its superior and inferior areas After giving off 2 large MH to the QL and supplying the caudate lobe (CL) the RH becomes reduced to a small vessel anastomosed with the AcRH The latter was 9 cm long 8 mm wide and coursed upward behind the portal vein (PV) and the common bile duct (CBD) and in the cystic triangle gave off the C before dividing into its terminal branches which most probably represent the anterior and the posterior segmental branches of the right lobe The anterior segmental artery is anastomosed with the celiac RH **This transverse anastomosis is the last extrahepatic communication between major hepatic arteries and is comparable with that existent at the hilus of the spleen between the lienal branches for inside the liver there is no anastomosis between the hepatic branches all arteries being end arteries**

The AcRH supplies the single short C (15 mm) without hazardous relations to the bile ducts and the blood vessels The rarity of this pattern is obvious from a study of individual constitutional variations illustrated in this atlas

There are 6 arterial arcades about the head of the pancreas The primary posterior arcade is made by the retroduodenal (RD) a branch of the GD and it becomes *united with the AcRH* from the SM via the second inferior pancreaticoduodenal (IPD) stemming from it A subsidiary arcade of the primary posterior arcade ends in the *first IPD derived from the AcRH* The primary outer anterior arcade *ends in the AcRH via its first IPD branch* Inner (upper) anterior pancreaticoduodenal arcade *joins the splenic (S)* via a branch of the dorsal pancreatic (DP) Descending from the first IPD of the AcRH is an artery *which forms an arcade with a jejunal branch (J) of the SM* The final arcade is made by the supraduodenal (SD) from which branches are distributed to the CBD the pancreas and the first part of the duodenum

There are 2 DP The lower one arises oddly from the second *jejunal branch* and ascends to the inferior surface of the pancreas where it bifurcates into the transverse pancreatic (TP) to the left and a right branch that unites with the superior pancreaticoduodenal (SPD) The upper DP from the S sends 1 branch to unite with the SPD another to join the TP The accessory left gastric *(AcLG) from the S anastomoses* with the recurrent branch of the left inferior phrenic (LIP) and with branches of the arc between the LH and the left gastric (LG) CD 5 cm HD 6 cm CBD 4 cm

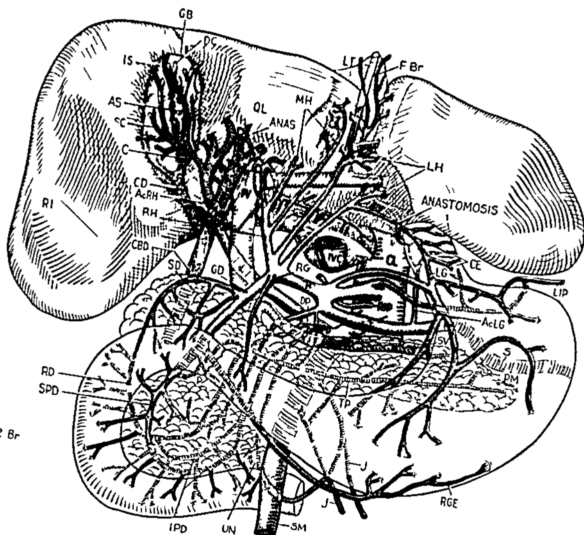


FIGURE 87

32 Br

Fig 88 Typical hepatolienogastric celiac trunk (CTr) (28 mm × 11 mm) and an accessory right hepatic (AcRH) which arises from the superior mesenteric (SM) and is anastomosed with the right hepatic (RH) in the cystic triangle Dual contiguous cystics (M W 74 yrs)

The common hepatic divides into its typical 3 branches the middle hepatic (MH) stemming from the *left hepatic* (LH) The celiac RH divides into its anterior and posterior segmental branches *for the anterior and the posterior segments* of the right lobe *The posterior segmental branch is anastomosed with an AcRH* (9 cm long 3 mm wide) *derived from the SM 30 mm from the latter s origin from the aorta (A)* The AcRH crossed the junction point of the cystic duct (CD) and the (HD) where surgically considered it could have been traumatized The anterior segmental branch of the RH gives off the dual cystic (C) arteries sites of their origin being contiguous The superficial cystic (SC) after a course of 33 mm leaves Calot s triangle by swerving caudad to the CD The deep cystic (DC 2 mm wide) courses upward its liver twigs being larger and more cryptically concealed than those of the SC It is this *DC which because of inattentive manipulation is prone to bleed profusely When cut the artery often retracts into the liver making its retrieval and tying difficult* and necessitating a suturing of hepatic tissue

The caudate process receives a branch from the RH which descends behind the portal vein (PV) the latter being 16 cm long The right and the left parts of the caudate lobe (CL) proper receive branches from the RH and the LH A common phenomenon especially to be remembered in pancreaticoduodenal resections is the fact that *a RH from the SM may give off the inferior pancreaticoduodenal (IPD)* Here both the anterior and the posterior pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) end in an AcRH via a short stem—i e a common IPD The supraduodenal (SD) makes a loop around the common bile duct (CBD) supplying it with twigs The dorsal pancreatic (DP) from the splenic (S) is typical giving transverse pancreatic (TP) to the left and 2 right branches of which one connects with the right gastro epiploic (RGE) and the other supplies the uncinate process (Un) The left gastric (LG) divides into its typical anterior and posterior branches the latter being anastomosed with the much smaller right gastric (RG)

The biliary tract was 13 cm long and 4 mm wide Angular type of union of the CD with the HD the CD opening posterolaterally CD 5 cm HD 5 cm CBD 8 cm

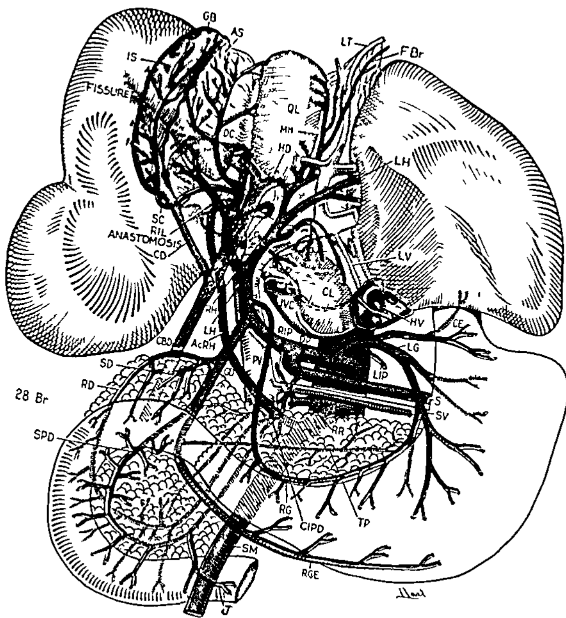

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RIL
ANASTOMOSIS
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LV
CL
IVC
RH
LH
HV
CE
CBD
AcRH
RIP
LG
SD
PV
LIP
RD
GD
28 Br
S
SV
RR
SPD
RG
TP
CIPD
SM
RGE
J

FIGURE 88

Fig 89 Complete tripod type of hepatolienogastric trunk (CTr) 35 mm x 8 mm) with an accessory right hepatic (AcRH) derived from the superior mesenteric (SM) and anastomosed with the celiac right hepatic (RH) Single cystic (C) Cystic triangle widely opened by dissection (M W 73 yrs)

The hepatic artery (H) divides into the (RH) the left hepatic (LH) and the middle hepatic (MH) As judged from casts showing the intrahepatic arrangement of arteries (Healey and Schroy) the LH divides into 2 main segmental branches viz the MH (medial segmental artery) that supplies the medial segment of the left lobe (QL) and the lateral segmental artery that divides into a superior and an inferior area artery for the respective superior and inferior areas of the lateral segment of the left lobe Of the 2 RH present in the cystic triangle the one from the celiac (CTr) most probably represents the anterior segmental artery for the anterior segment of the right lobe the AcRH (9 cm long 4 mm wide) from the SM represents the posterior segmental artery for the posterior segment

The 2 RH are anastomosed in the cystic triangle by a large vessel (3 mm wide 15 mm long) which courses parallel with the C and with which it surgically considered could have been confused This anastomosis represents the last extrahepatic communication between the hepatic branches for inside the liver no major arterial anastomosis takes place

The C crossed the AcRH ventrally and ran a course parallel with that of the cystic duct (CD) for 3 cm before dividing into its superficial (SC) and deep (DC) branches Note the surgical hazards involved by the AcRH derived from the SM In its long course to the cystic triangle it passed behind the portal vein (PV) the common bile duct (CBD) the cystic duct (CD) and the C The entire caudate lobe (CL) is supplied by a branch of the RH that descended behind the PV and was anastomosed with the LH via its lateral segmental branch Of 29 hepatic terminals shown 4 stem from the MH 7 from the LH and the rest from the RH

The anterior and the posterior pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and the RD unite with the SM via a common inferior pancreaticoduodenal (CIPD) Thrombosis of the SM above the point of origin of the AcRH allows for collateral circulation to be established via the AcRH and may be the reason why certain individuals survive blockage of the beginning of the SM The dorsal pancreatic (DP) here oddly derived from the AcRH gives off the transverse pancreatic (TP) and communicates with the retroduodenal (RD) There are 2 supraduodenals (SD) Commencement of the hepatic duct (HD) represents a late i e a retarded union of some of the area ducts CD 3 cm HD 4 cm CBD, 8 cm

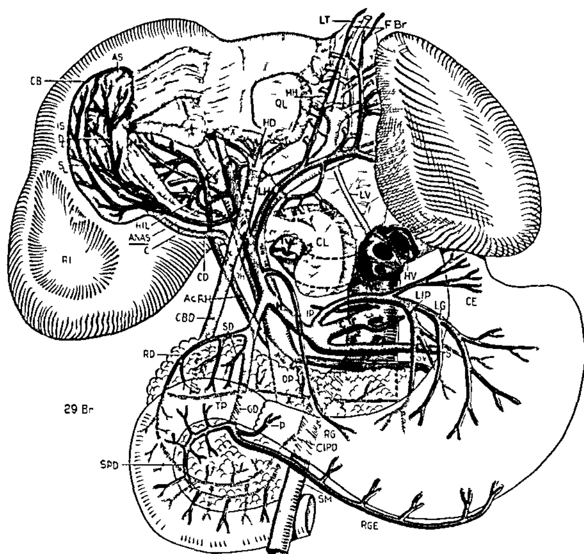

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HIL
ANAS
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CD
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AcRH
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LG
CE
CBD
IP
SD
RD
S
DP
29 Br
TP
GD
D
RG
CIPD
SPD
SM
RGE

FIGURE 89

FIG 90 Complete hepatolienogastric celiac trunk (CTr) (30 mm x 12 mm) with an accessory right hepatic (AcRH) from the superior mesenteric (SM) the latter supplying the posterior segment of the right lobe and giving origin to the superficial cystic (SC) Dual cystics (C) (M W adult)

The celiac right hepatic (RH) after giving off the left hepatic (LH) the right gastric (RG) 2 middle hepatics (MH) and the deep cystic (DC) courses dorsal to the hepatic duct (HD) The AcRH (7 cm long) derived from the SM courses behind the portal vein (PV) and the junction point of the cystic duct (CD) with the HD and breaks up into several branches that enter side walls of the fissured area under the gallbladder (GB) Upon deep probing surgically considered these branches covered by omental tissue and obviously not to be interfered with could be exposed and mistaken for the C The dual C arise from 2 different RH The SC is short (10 mm) and stems from the AcRH in the cystic triangle the DC is much longer (35 mm) and arises outside the triangle from the RH to the left of the HD

The caudate process is supplied by a branch of the RH the right and the left parts of the caudate lobe (CL) proper by 2 branches of the LH The supraduodenal (SD) forms a scalloped arcade from which branches are distributed to the common bile duct (CBD) and the first part of the duodenum There are 2 anterior and 2 posterior pancreaticoduodenal arcades The inner smaller anterior arcade begins with the dorsal pancreatic (DP) here *oddly derived from the left inferior phrenic (LIP)* and ends in the second *jejunal* branch stemming from the *left side of the SM* The lower the outer and the larger anterior arcade made by the superior pancreaticoduodenal (SPD) ends in the first *jejunal branch (J) again to the left of the SM* The small upper posterior arcade begins and ends in a retroduodenal (RD) *derived from the AcRH* The second (lower) posterior arcade joins the second J *The fact that both anterior and posterior arcades often end in inferior pancreaticoduodenal (IPD) arteries derived from the first jejunal branches makes the inspection of the latter an advisable procedure in resections lest by severance of these (J) the blood supply to the duodenum the head of the pancreas and the first part of the jejunum become impaired* Worthy of note is the fact that the LIP here is associated with the blood supply of the head of the pancreas (via its DP branch) and with that of the esophagus (via the cardio-esophageal CE rami of its recurrent esophageal branch)

The CD (30 mm long 6 mm wide) opened posterolaterally forming an angular type of union with the HD HD 1 cm CBD 7 cm

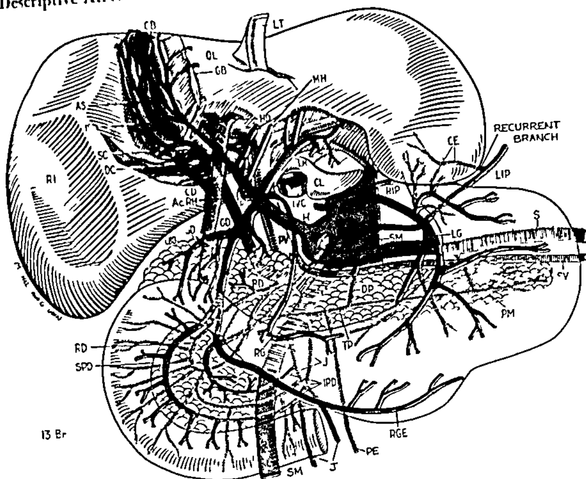

CD
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RECURRENT
BRANCH
CE
LIP
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IVC
RIP
H
S
GD
PV
SM
LG
PD
DP
CV
PM
TP
RD
SPD
RG
J
IPD
13 Br
RGE
PE
J
SM

Figure 90

FIG 91 Complete hepatolienogastric celiac trunk (CTr) (30 mm x 10 mm) and an accessory right hepatic (AcRH) derived from the gastroduodenal (GD) via its retroduodenal (RD) branch Single cystic (C) (M W adult)

The right hepatic (RH) (6 mm wide) divides to the left of the hepatic duct (HD) into its 2 main segmental branches of the right lobe the uppermost probably being the anterior the lower (the right inferior lobular RIL) the posterior segmental branch The HD thereby is placed in a precarious surgical position for there is an artery *in front* of it and one *behind* it The left hepatic (LH) proceeds to the lateral segment of the left lobe where it divides into its superior and inferior area branches the former supplying a falciform branch The middle hepatic (MH) from *the anterior segmental branch of the RH* becomes resolved into several area branches for the medial segment of the liver and supplies the entire caudate lobe (CL)

The cystic triangle presents a surgical hazard in that the posterior segmental branch of the RH (RIL) that enters the fissured area could *upon deep probing of omental tissue have been mistaken for the C* which arose from it and was 3 mm wide Inattentive manipulation of the C and the cystic duct (CD) here might have resulted in injury to the HD and a main liver artery *An AcRH derived from the CD via its RD branch (RD) enters the fissured area* The possibility of an artery coursing caudad to the CD should always be borne in mind for frequently such an artery is the superficial cystic (SC) or the entire cystic derived from the GD the RD or even from the superior mesenteric (SM) (Belou 1915)

The RD arose jointly with the AcRH from a GD by a common stem 1 mm wide The posterior pancreaticoduodenal arcade formed by the RD became united with the SM via its own inferior pancreaticoduodenal (IPD) derived from a *jejunal branch (J) which arose from the left side of the SM* The anterior arcade made by the superior pancreaticoduodenal (SPD) ended in an IPD derived from the SM at *a higher level* than that of the posterior arcade The supraduodenal (SD 3 mm wide) a branch of the common stem for the AcRH and the RD *had an extensive distribution* In addition to supplying the intrapancreatic portion of the common bile duct (CBD) and the first part of the duodenum it formed loops on the anterior surface of the head of the pancreas from which a branch extended to the left to unite with the dorsal pancreatic (DP) The transverse pancreatic (TP) sprang from the GD and was anastomosed with the DP and with the a pancreatica magna (PM) of the splenic (S)

The CD (25 mm long 5 mm wide) opened posterolaterally forming a sharp angle with the HD HD 4 cm CBD 7 cm

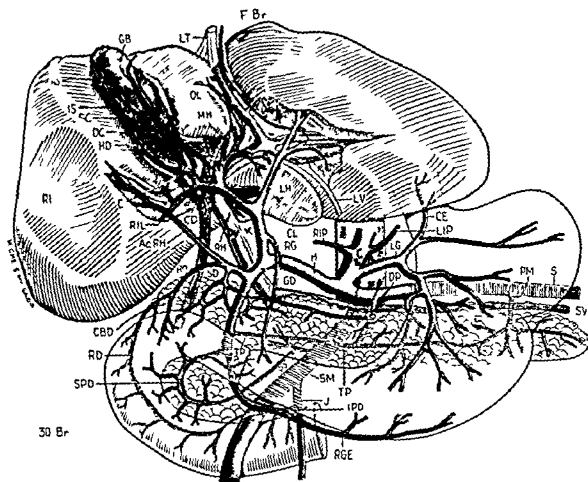

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CBD
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TP
J
IPD
RGE
30 Br

FIGURE 91

Fig 92 A case in which the gallbladder (GB) had been removed some time during life The stump of the cystic (C) and that of the cystic duct (CD) could still be seen Hepatolienopancreatic celiac trunk (CTr) with separate origin of the left gastric (LG) from the aorta (A) (M W 64 yrs)

The liver was very oddly shaped the left lobe being fusiform the right lobe quadrangular and the quadrate lobe (QL) long and narrow The left surface of the right lobe was overlain by the left lobe The liver was dissected along the line of the ligamentum teres (LT) exposing the hepatic terminals and a large hepatic vein (HV) which oddly was near the surface and picked up 9 tributaries The stump of the CD was 20 mm long 4 mm wide Firmly attached to it was the C (15 mm × 2 mm) which had crossed the hepatic duct (HD) and was a branch of the right hepatic (RH) *The CTr (15 mm × 10 mm) ended* by giving off the hepatic (H) the splenic (S) and the dorsal pancreatic (DP) at the same point thus forming a tripod but not that of Barkow or of Haller for the origin of the LG was shifted to the A

The common hepatic (H 8 mm) after giving off the gastroduodenal (GD) (6 mm) became the hepatic artery proper from which arose the left (LH) and the middle (MH) hepatics (for the lateral and the medial segments of the left lobe) and the RH for the anterior and the posterior segments of the right lobe as judged from casts The LH (5 mm) gave off its superior *and inferior area branches for the* respective areas of the lateral segment of the left lobe The inferior area branch of the LH (upper in illustration) supplied a MH to an inferior area of the medial segment (QL) as the superior area of the medial segment was vascularized by another MH stemming from the RH—this *again as judged from casts As commonly* is the case the RH (7 mm) divided to the left of the HD into its 2 purported main branches the upper for the anterior segment the lower for the posterior segment of the right lobe *thus placing 2 RH within the boundaries of the cystic triangle*

The *caudate lobe (CL) received its* blood supply from a branch of the RH that descended behind the portal vein (PV) to become distributed to the CL via 3 branches one for the caudate process one for the right and one for the left halves of the CL proper Of the 30 terminal hepatics dissected 9 came from the RH and the LH the remaining were concerned with the blood supply of the medial segment of the left lobe and the CL

The dual posterior pancreaticoduodenal arcades made by the retroduodenal (RD) ended in the superior mesenteric (SM) via a common inferior pancreaticoduodenal (IPD) *The lower anterior arcade joined the first jejunal branch (J) from the left side of the SM* and was anastomosed with a branch of the IPD The upper anterior pancreaticoduodenal arcade made by a branch of the superior pancreaticoduodenal (SPD) joined the DP from the CTr

The stump of the CD was 2 cm HD 3 5 cm CBD 7 cm

FIGURE 92

Fig 93 Another case in which the gall bladder (GB) had been removed during life The stump of the cystic duct (CD) and the stem of the cystic artery (C) were plainly discernible at dissection Separate origin of the hepatic (H) from the aorta (M N 55 yrs)

The cut cystic was a branch of the left hepatic (LH) and was 15 mm long and 2 mm wide The stump of the CD measured 1 cm the C being adherent to it The common hepatic (H 8 mm) arose separately from the A (3 cases in 200 bodies) The left gastric (LG) (4 mm) and the splenic (S) (9 mm) arose jointly from a lienogastric trunk (5 5%) The H ended by dividing into 5 branches [viz the LH the right hepatic (RH) the gastroduodenal (GD) the retroduodenal (RD) the supraduodenal (SD)] all arising at nearly the same point The LH (7 mm) after giving off the middle hepatic (MH) (4 mm) to the medial segment of the left lobe divided into its superior and inferior area branches of the lateral segment of the left lobe A ramus of the inferior area branch supplied the falciform ligament The MH for the medial segment of the left lobe (QL) became resolved into 3 main branches each of which gave off fine liver twigs seen only when Glisson s capsule was removed Distally it sent a ramus to the falciform ligament

The RH (8 mm) in the cystic triangle divided into its purported anterior and posterior segmental branches these subdividing before entering the liver The major blood supply to the caudate lobe (CL) came from a branch of the RH that ascended anterior to the portal vein (PV) then descended behind it giving branches to the caudate process and the CL proper *The number of terminal hepatics dissected was unusually high* (56 as opposed to 20 to 30 in 90% 30 to 40 in 10% of cases) Many of them ran a course under Glisson s capsule anastomosing before entering the liver *The anatomy and the functional significance of these subcapsular twigs remain a major unsolved problem for in plastic casts they do not show up the arteries being too small to carry injected material*

The gastroduodenal (GD 5 mm) trifurcated as it frequently does the extra ramus *being a large pyloric branch (P)* The anterior and the posterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) and the RD joined the superior mesenteric (SM) via a common inferior pancreaticoduodenal (CIPD) that supplied a jejunal branch (J) to the first part of the jejunum The SD supplied the common bile duct (CBD) and the first part of the duodenum and gave off a 1 mm wide branch that coursed along the anterior surface of the P to anastomose with the dorsal pancreatic (DP) from the S Another branch descended behind the first part of the duodenum to unite with the RD arcade Of the dual DP the one from the H descended behind the splenic vein (SV) and gave off the transverse pancreatic (TP) that anastomosed with the a pancreatica magna (PM) of the S The DP from the S sent a second TP to the left and a branch to the right that united with the SD The lienogastric trunk (9 mm wide) gave rise to the inferior phrenics (P)

Stump of CD 1 cm HD 4 cm CBD 5 cm

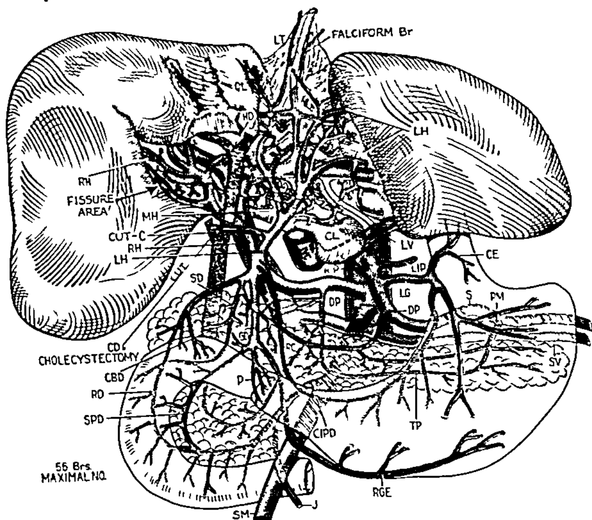

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CUT-C
RH
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CL
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SD
DP
LG
S
PM
DP
CD
CHOLECYSTECTOMY
SV
CBD
P
RD
SPD
TP
CIPD
56 Brs.
MAXIMAL NO.
RGE
J
SM

FIGURE 93

FIG 93 Another case in which the gall bladder (GB) had been removed during life The stump of the cystic duct (CD) and the stem of the cystic artery (C) were plainly discernible at dissection Separate origin of the hepatic (H) from the aorta (M N 55 yrs)

The cut cystic was a branch of the left hepatic (LH) and was 15 mm long and 2 mm wide The stump of the CD measured 1 cm the C being adherent to it The common hepatic (H 8 mm) arose separately from the A (3 cases in 200 bodies) The left gastric (LG) (1 mm) and the splenic (S) (9 mm) arose jointly from a lienogastric trunk (5 5%) The H ended by dividing into 5 branches [viz the LH the right hepatic (RH) the gastroduodenal (GD) the retroduodenal (RD) the supraduodenal (SD)] all arising at nearly the same point The LH (7 mm) after giving off the middle hepatic (MH) (4 mm) to the medial segment of the left lobe divided into its superior and inferior area branches of the lateral segment of the left lobe A ramus of the inferior area branch supplied the falciform ligament The MH for the medial segment of the left lobe (QL) became resolved into 3 main branches each of which gave off fine liver twigs seen only when Glisson s capsule was removed Distally it sent a ramus to the falciform ligament

The RH (8 mm) in the cystic triangle divided into its purported anterior and posterior segmental branches these subdividing before entering the liver The major blood supply to the caudate lobe (CL) came from a branch of the RH that ascended anterior to the portal vein (PV) *then descended behind it giving branches* to the caudate process and the CL proper *The number of terminal hepatics dissected was unusually high* (56 as opposed to 20 to 30 in 90% 30 to 40 in 10% of cases) *Many of them ran a course under* Glisson s capsule anastomosing before entering the liver *The anatomy and the functional significance of these subcapsular twigs remain a major unsolved problem for in plastic casts they do not show up the arteries being too small to carry injected material*

The gastroduodenal (GD 5 mm) trifurcated as it frequently does the extra ramus *being a large pyloric branch (P)* The anterior and the posterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) and the RD joined the superior mesenteric (SM) via a common inferior pancreaticoduodenal (CIPD) that supplied a jejunal branch (J) to the first part of the jejunum The SD supplied the common bile duct (CBD) and the first part of the duodenum and gave off a 1 mm wide branch that coursed along the anterior surface of the P to anastomose with the dorsal pancreatic (DP) from the S Another branch descended behind the first part of the duodenum to unite with the RD arcade Of the dual DP the one from the H descended behind the splenic vein (SV) and gave off the transverse pancreatic (TP) that anastomosed with the pancreatica magna (PM) of the S The DP *from the S sent a second TP* to the left and a branch to the right that united with *the SD The lienogastric trunk (9 mm* wide) gave rise to the inferior phrenics (P)

Stump of CD 1 cm HD 4 cm CBD 5 cm

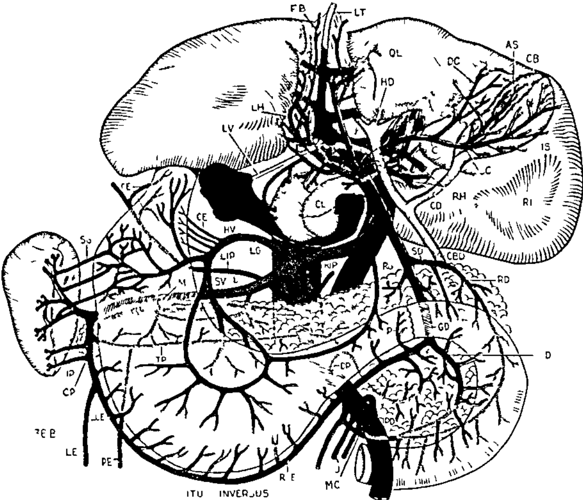

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SU
CBD
RD
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D
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ID
CP
LE
PE
RE
MC
ITU INVERSUS

FIGURE 94

FIG 94 A case of complete situs inversus of the supramesocolonic organs i e a body in which the organs normally present on the left side were transposed to the right side and vice versa Complete hepatolienogastric celiac trunk (CTr) Single cystic (C) (M N 45 yrs)

This case of *situs viscerum inversus* or mirror image (transposition) of both the thoracic and the abdominal organs was encountered and dissected by Dr N Verano a Ross V Paterson Fellow in Anatomy at Jefferson Medical College it being the first and only such specimen observed in the dissecting rooms of the Daniel Baugh Institute of Anatomy of Jefferson Medical College As dissected and depicted by the author the supracolonic blood vessels showed *no marked variation other than being transposed* The celiac (CTr) was a typical tripod hepatolienogastric trunk (20 x 10 mm) The common hepatic (H 8 mm) after giving off the gastroduodenal (GD) (5 mm) became the hepatic artery proper which distally gave off the right (RH) the left (LH) and the middle (MH) hepatics nearly at the same point The RH (6 mm) divided into its purported segmental branches to the right of the hepatic duct (HD) Its anterior segmental branch swung behind the portal vein (PV) and ascended to the anterior segment its posterior segmental branch coursed in front of the PV and before passing under the HD divided into 2 branches that entered the fissured area under the gallbladder (GB)

The C arose from the upper division of the posterior segmental branch and after coursing 2 5 cm divided into its superficial (SC) and deep branches (DC) The LH (5 mm) divided into its purported superior and inferior area branches of the lateral segment of the left lobe the inferior area branch supplying a ramus to the falciform ligament The MH for the medial segment of the left lobe (QL) arose from the anterior segmental branch of the RH before it swung under the PV It too gave off a falciform branch The caudate lobe (CL) received arteries from the anterior segmental branch of the RH at 3 sites to wit one artery for the caudate process 2 for the left and 2 for the right half of the caudate lobe proper (CL) Of 36 hepatic terminals 10 entered the CL

The anterior and the posterior pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and by the retroduodenal (RD) united in a common inferior pancreaticoduodenal (CIPD) which instead of arising from the superior mesenteric (SM) (9 mm wide) took origin from its first jejunal branch The supraduodenal (SD) arose from the RD Of the 2 dorsal pancreatics (DP) the main one sprang from the SM ascended to the inferodorsal surface of the pancreas where it divided into the transverse pancreatic (TP) and a right branch that joined the right gastroepiploic (RGE) The smaller DP united with the a pancreatica magna (PM) The magistral splenic (6 mm) divided into 11 lienal branches the lower terminal showing an *extrasplenic transverse anastomosis* The left gastric (LG) (4 mm) gave off 4 posterior cardioesophageal branches (CE) these being augmented by CE branches from the recurrent branch of the left inferior phrenic (LIP) The medial segmental duct joined the HD CD 3 cm HD 4 cm CBD 8 cm

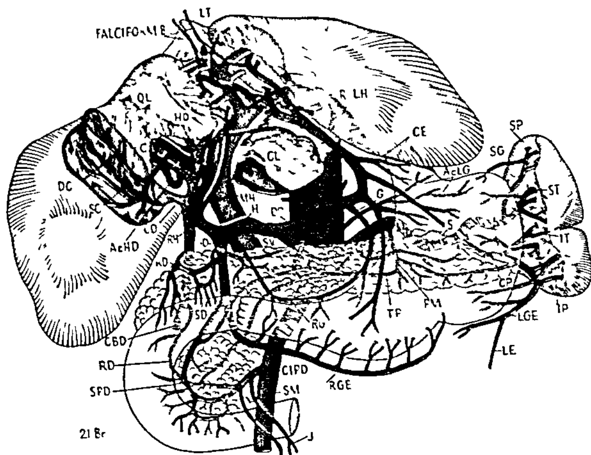

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H
DC
G
AcLG
ST
SC
S
LD
RH
AcHD
IT
RD
SV
CP
SD
TP
RG
LGE
LP
CBD
LE
RD
CIPD
SPD
RGE
SM
21 Br
J

FIGURE 93

Fig 95 Incomplete hepatolienogastric celiac trunk with the entire left hepatic (ReLH) *replaced from the left gastric (LG)* An accessory left gastric (AcLG) from the splenic (S) Single cystic (C) crossing large accessory hepatic duct (AcHD) (M W adult)

The right hepatic (RH) lies anterior to the common bile duct (CBD) for a short stretch and after giving off the middle hepatic (MH) passes behind the hepatic duct (HD) to enter the cystic triangle Here it divides into its purported anterior and posterior segmental branches for the anterior and the posterior segments of the right lobe *thus placing 2 RH in the triangle* The lower branch of the RH makes a downward *caterpillarlike loop below a large AcHD The C has a high origin* Arising from the anterior segmental branch of the RH it crosses the AcHD and the posterior segment branch of the RH In a cholecystectomy accurate identification of the C the posterior segment branch of the RH and the AcHD is essential lest there ensue *disconcerting postoperative effects* The large left hepatic (ReLH) arises from the LG making the latter a hepatogastric artery (Haller 1752) Here the superior area branch of the replaced left hepatic (ReLH) sends a large branch *to the quadrate lobe (QL) as a substitute* blood supply to that not coming from the MH derived from the RH Both falciform branches take origin from the ReLH

The anterior and the posterior pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) end in the superior mesenteric (SM) via a common inferior pancreaticoduodenal (CIPD) *which gives off jejunal branches* The RD passes at first *in front* then behind the CBD supplying the latter with arterial twigs The subsidiary arcade from the RD supplies a *shower of twigs* to the first part of the duodenum The dorsal pancreatic (DP) takes origin from the celiac artery (CA) (22%) Passing down behind the splenic vein (SV) *near the junction point of the latter with the superior mesenteric vein (SMV)* it gives off 2 branches to the right and 1 to the left One of the right branches passes anterior to the SMV to unite with the SPD the other passes dorsal to the SMV to supply the uncinate process (Un) The branch to the left—the transverse pancreatic (TP) —courses along the inferior surface of the pancreas where it unites with the arteria pancreatica magna (PM) from the S and with the caudal pancreatic (CP) from the left gastro epiploic (LGE) which here falls short of anastomosis with the right gastro-epiploic (RGE) The posterior cardio esophageal (CE) region of the stomach receives a copious blood supply from the AcLG via the *ramus esophagogastricus posterior ascendens* of the S Distally this ramus anastomoses with the short gastrics (SG) from the S and with the CE branches from the ReLH The caudate lobe (CL) *is supplied by a branch from the RH* that passes behind the left branch of the portal vein (PV) It is anastomosed with the ReLH and thereby could effect a collateral pathway outside the liver between the RH and the LH in the event the hepatic (H) were ligated Distributed splenic vascularization with 2 inferior polar arteries (IP) and a superior polar artery (SP)

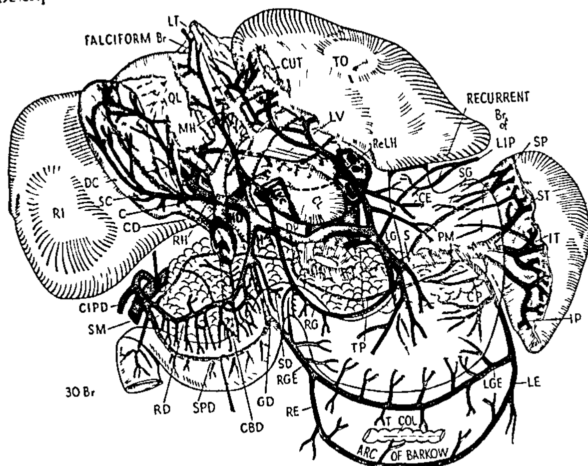

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LE
30 Br
RD
SPD
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CBD
T COL
ARC
OF BARKOW

FIGURE 96

FIG 96 Typical incomplete hepatolienogastric celiac trunk the entire left hepatic (ReLH) arising from the left gastric (LG) Single cystic (C) with a very short stem (M W 59 yrs)

The celiac artery (size 25 mm x 10 mm) gives rise only to the right (RH) and the middle (MH) hepatics The left hepatic (ReLH) after its origin from the LG gives off cardio-esophageal branches (CE) *that unite with similar branches from the recurrent branch of the left inferior phrenic (LIP) and with short gastrics (SG) from the splenic terminals* Distally the ReLH divides into purported superior and inferior area branches of the left segment of the left lobe the superior area branch (lower in the drawing) sends a ramus to the quadrate lobe (QL) and to the falciform ligament

The MH oddly gives origin to the right gastric (RG) After crossing the left hepatic duct (HD) anteriorly it supplies the QL and ends in 2 falciform branches The RH and the C have a typical *textbook pattern* of orientation in the cystic triangle of Calot or of Belou Distally the RH divides into 2 branches which most probably are the anterior and the posterior segmental branches of the right lobe judged from casts of arteries The caudate lobe (CL) receives a branch from the RH for its caudate process and a much larger branch from the anterior segmental branch of the RH for the 2 parts of the CL proper

The duodenum has been turned forward *to show the copious blood supply which its posterior wall receives from the retroduodenal arcade made by the retroduodenal (RD)* A ramus of the arcade is anastomosed with the dorsal pancreatic (DP) from the splenic (S) The anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) joins the superior mesenteric (SM) via a common inferior pancreaticoduodenal (CIPD) The supraduodenal (SD) arises from the right side of the gastroduodenal (GD) The DP shows a typical origin from the first part of the S (29%) Its left transverse pancreatic branch (TP) unites with the caudal pancreatic (CP) from the left gastro-epiploic (LGE) and with the a pancreatica magna (PM) of the S

The right and the left gastro-epiploics (RGE LGE) unite to form the infragastric arterial arc A right epiploic (RE) from the RGE and a left epiploic (LE) from the LGE unite to form the *arcus epiploicus magnus of Barlow* situated in the back wall of the great omentum below the transverse colon The S is of the *distributed* type In addition to its superior (ST) and inferior (IT) terminals it gives off a long superior polar (SP) and a large inferior polar (IP) Twenty lienal branches enter the spleen and 30 hepatic terminals enter the liver

As judged from the casts of Healey and Schroy the right HD receives the anterior and the posterior segmental ducts from the right lobe The left HD receives the medial segmental duct from the medial segment (QL) and the lateral segmental duct (with superior and inferior area divisions) from the left lobe The cystic duct (CD) swerves posteriorly CD 4 cm HD 5 cm CBD 8 cm

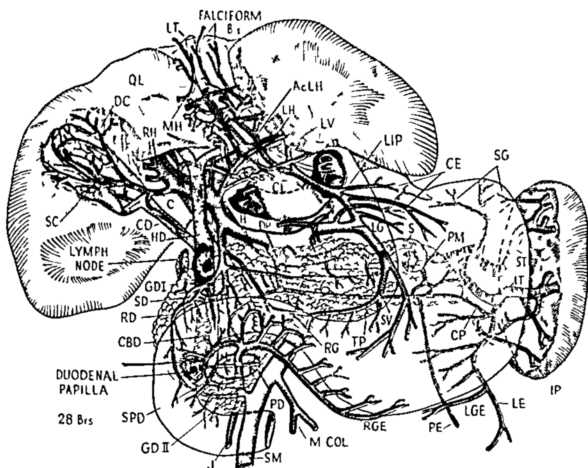

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DC
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RH
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LG
S
PM
HD
LYMPH
NODE
ST
IT
GDI
SD
RD
SV
CBD
RG
TP
CP
DUODENAL
PAPILLA
IP
LE
28 Brs
SPD
PD
LGE
RGE
PE
M COL
GD II
SM
J

FIGURE 97

Fig 97 Hepatolienogastric celiac trunk the splenic (S) (lienal) here oddly arising from the hepatic (H) An accessory left hepatic (AcLH) given off by the left gastric (LG) *The gastroduodenal (GD) and* the right gastro-epiploic (RGE) from the superior mesenteric (SM) (M N 57 yrs)

Since the left hepatic (LH) from the celiac hepatic (H) was small (purportedly supplying but a subdivision of the superior area of the lateral segment of the left lobe) the main blood supply of the lateral segment was furnished by an AcLH from the LG After supplying the superior and th inferior area branches for the lateral segment of the left lobe the AcLH sent a branch across the umbilical fossa to partake in the blood supply of the medial segment (QL) furnished mainly by 2 middle hepatics (MH) from the celiac right hepatic (RH) *Falciform branches from the AcLH furnished a collateral route between branches of the internal mammary and the LG* The cystic artery (C) (2 mm wide 2 5 cm long) divided *into* its superficial (SC) and deep (DC) branches these being united The 2 small branches of the RH in the cystic triangle most probably represent arteries for the posterior segment of the right lobe as judged from 150 liver casts made by Healey and Schroy

Surgically *considered it is important to know* that *the gastroduodenal (GD II) like the hepatic trunk, may take origin from the SM and pass through the head of the pancreas as here* Upon reaching the ventral surface of the pancreas the GD II divided into the superior pancreaticoduodenal (SPD) and the RGE The gastroduodenal (GD I) of hepatic origin resolved itself into the right gastric (RG) the retroduodenal (RD) the supraduodenal (SD) a branch that communicated with the RGE and a branch that coursed leftward on the ventral surface of the pancreas The dorsal pancreatic (DP) from the first part of the S (39%) supplied the transverse pancreatic branch (TP) that anastomosed with the a pancreatica magna (PM) of the S and with the caudal pancreatic (CP) of the left gastro epiploic (LGE) and along its course gave off a posterior epiploic branch (PE) to the transverse mesocolon (TrCol)

The tortuous splenic was 18 cm long nearly twice the length it need be Since it divided early into its terminal lienal branches it constituted *a distributed type of S* giving rise to inferior polars (IP) and to the LGE which here was not anastomosed with the RGE The cardio esophageal (CE) region of the stomach showed extensive anastomoses between the CE branches of the AcLH the LG and the short gastrics (SG) of the S The caudate lobe (CL) was supplied by a branch of the RH that passed behind the portal vein (PV) and by a branch from the LH

The cystic duct (CD) joined the hepatic duct (HD) posteriorly identification of 2 ducts being complicated by the presence of the lymph node of Terrier or of Luschka (LN) CD 5 5 cm HD 6 cm CBD 3 cm

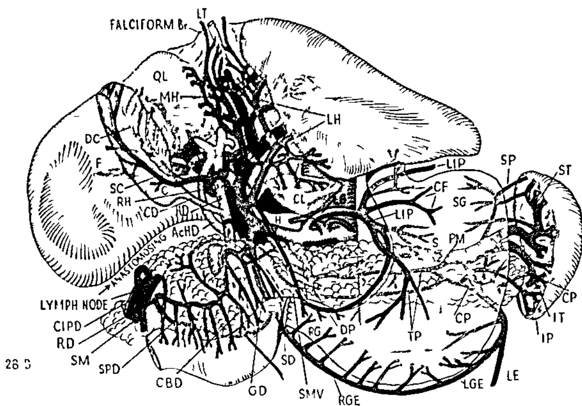

FALCIFORM Br.
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RH
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ANASTOMOSING
LYMPH NODE
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SPD
CBD
GD
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PM
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ST
CP
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TP
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28 D

Figure 98

FIG 98 Very odd and surgically considered very dangerous pattern of a right hepatic (RH) making a complete circle around the hepatic duct (HD) and dividing into 2 branches one coursing anterior the other posterior to the portal vein (PV) A large accessory hepatic duct (AcHD) joins the right HD with the common bile duct (CBD) (M N 80 yrs)

Preliminary study of this nearly unbelievable case gave the impression that the RH passed through a split HD the length of the HD being 4 cm the extent of the split being 3 cm Subsequent study by the injection of colored fluid showed that the HD was not split The extra bile duct to the right of the HD represents a type of anastomosing biliary ducts in this case it effected an anastomosis between the right branch of the HD and the CBD Surgical hazards in cholecystectomy (1) the RH after winding around the HD divides into 2 branches one coursing anterior, the other posterior to the portal vein (PV) (2) the cystic artery (C) crosses an AcHD anteriorly (3) the cystic duct (CD) crosses the AcHD anteriorly and joins the HD cephalad to the junction point of the AcHD with the CBD Of 500 bodies examined *this cystic triangle constituted the most bizarre fashioned pattern and amazed every surgeon who studied the specimen* as demonstrated at the Centennial Meeting of the American Medical Association at Atlantic City in 1947

The RH divided into its purported anterior and posterior segmental branches for the respective anterior and posterior segments of the right lobe *division in thi* case being oddly effected to wit the pos terior segmental branch passed dorsal th anterior segmental branch ventral to th PV The middle hepatic (MH) from th RH crossed the PV and distally broke u into branches that supplied the medial seg ment of the left lobe (QL) ending in falc form branches After giving off its superio area branch to the left segment of the lef lobe the LH proceeded under branche of the left PV to end in the inferior are branch of the left segment of the left lob and in the falciform branches

The duodenum is turned forward to show the retroduodenal (RD) arcade and the ramifications of its branches It picked up the anterior pancreaticoduodenal arcade made by the superior pancreaticoduodenal (SPD) whereupon both arcades joined the superior mesenteric (SM) via a common inferior pancreaticoduodenal (CIPD) The dorsal pancreatic (DP) gave off 2 transverse pancreatic branches (TP) that united with the a pancreatica magna (PM) of the splenic (S) and with the caudal pancreatic (CP) of the left gastroepiploic (LGE) To the right it united with the RD via a branch that passed behind the PV The left inferior phrenic (LIP) arose from the left gastric (LG) supplying the cardio esophageal (CE) branches Distributed S gave off 18 lienal branches The caudate lobe (CL) was supplied by 2 branches of the RH and 1 branch of the LH these being anastomosed CD 2 5 cm HD 4 cm CBD 6 cm

Figure 99

Fig 99 Huge gallbladder (GB) and *immensely dilated bile ducts due to a biliary* obstruction caused by *cancer of the duodenum* A gastrojejunostomy had been performed (M W 60 yrs)

Upon opening the abdomen a large cancerous mass (7 x 9 cm) was found along the concave surface of the duodenum part of it involving the head of the pancreas The huge GB was 9 cm long and 7 cm wide the hepatic duct (HD) was widely dilated (3 to 4 cm) for the greater part of its extent (5 cm long) Upon reaching the region of the duodenum it became narrowed to 2 5 cm The dilated cystic duct (CD) (7 cm long and 1 5 cm wide) opened posteriorly into the HD being *united with the latter for 1 5 cm*

About the suture lines of the gastrojejunostomy regional blood vessels had become enlarged and *new communications* had been established To the left a branch of the dorsal pancreatic (DP) from the splenic (S) descended below the pancreas to supply the left colic flexure thereby *functioning as an accessory middle colic (AcMCol)* Along the colon a branch of the DP anastomosed with the left branch of the middle colic (MCol) forming an arcade that united with the ascending branch from the inferior mesenteric To the right a jejunal branch of the common inferior pancreaticoduodenal (CIPD) after picking up a branch from the DP supplied the jejunum distal to the point of suture lines

The immensely dilated HD afforded an excellent opportunity to study its blood supply The latter was furnished by (1) the ascending branches of the retroduodenal (RD) (2) the ascending branch of the cystic (C) (3) a branch of the right hepatic (RH) that descended behind the HD Branches of the RD formed an extensive plexus on the *anterior and the posterior* surfaces of the HD and anastomosed with twigs from the C which here arose to the left of the HD crossing it anteriorly Injury of the blood vessels to the common bile duct (CBD) from the RD and the supraduodenal (SD) may cause necrosis of the common duct as concluded from cases observed by Appleby of Vancouver Canada (1954) (Personal communication)

The pattern of the celiac axis was typi*cal there being a RH a middle (MH) and* a left (LH) hepatic The S (magistral type) gave off a short accessory left gastric (AcLG) The left gastric (LG) gave off 3 cardio esophageal branches (CE) and the left inferior phrenic (LIP) that here oddly crossed the esophagus anteriorly supplying the CE region The pancreaticoduodenal arcades made by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) ended in a common IPD The anterior arcade was *united with a branch from* the DP that passed behind the superior mesenteric vein (SMV) The DP from the S *descended below the pancreas to function as an AcMCol for the left colic flexure thereby constituting the artery of Riolan* The caudate lobe (CL) was supplied by 3 branches 2 from the RH and 1 from the LH CD 7 cm HD 5 cm CBD 5 cm

Fig. 100 (*Continued from preceding page*)

shown accounted for the survival of patients on whom the respective operations were performed.

I. Routes through the H arteries arising from sources other than the common celiac hepatic trunk (CTr). (1) The accessory left hepatic (AcLH) from the left gastric (LG). (2) The accessory right hepatic (AcRH) from the superior mesenteric (SM).

II. Nonhepatic routes capable of connecting with branches of the severed hepatic arteries. (1) The infragastric via the right (RGE) and the left (LGE) gastroepiploics and the gastroduodenal (GD) to the right and the short gastrics (SG) to the left. (2) The supragastric via the right (RG) and the left (LG) gastrics. (3) The infracolic via the arc of Barkow in the posterior layer of the great omentum: blood may be routed directly into the GD through the RGE and the right epiploic (RE) in Type I; indirectly into it via the posterior epiploic (PE), the transverse pancreatic (TP) and its connections in Type II. The left limb of the arc is always made by the left epiploic (LE). (4) The paraesophageal hepatogastric. Cardio-esophageal branches (CE) from the LG and the S via its SG unite with similar branches from the AcLH. (5) The retroesophageal. The recurrent branch of the left inferior phrenic (LIP) gives off CE branches which unite with those derived from the AcLH, the (SG) and the accessory left gastric (AcLG). (6) The transpancreatic. Blood leaving the S through the dorsal pancreatic (DP) or the arteria pancreatica magna (PM) and the caudal pancreatic (CP) or coming from the arc of Barkow through a PE enters the TP via which it may course into the superior pancreaticoduodenal (SPD), the RGE or the GD to reach the hepatic trunk (H).

III. Routes over arteries outside the celiac blood supply. (1) The SM via the common inferior pancreaticoduodenal and the anterior and the posterior pancreaticoduodenal arcades respectively made by the superior pancreaticoduodenal (SPD) and the retroduodenal branches of the GD. (2) The SM via its TP branch which may connect with the SPD, the RGE or the GD. (3) Inferior phrenics coursing in the diaphragm may unite with branches of the H at attached areas of the liver. CE branches of the recurrent branch of the LIP anastomose with subcapsular branches of the H in the fossa for the ligamentum venosum (LV). (4) The superior phrenics from the terminal branches of the internal mammary, i.e., the superior epigastric and the musculophrenic communicate with branches of the H in the diaphragm. (5) The ensiform branch of the internal mammary (of Haller and Petren) coursing in the falciform ligament and the ligamentum teres (LT) unite with the terminal falciform branches given off by the left (LH) and the middle (MH) hepatic. (6) Vasa vasorum. An arteriole derived from the right inferior phrenic (RIP) courses upward to the liver along the inferior vena cava (IVC). (7) Supply along the biliary ducts by the arteriole derived from the retroduodenal artery.

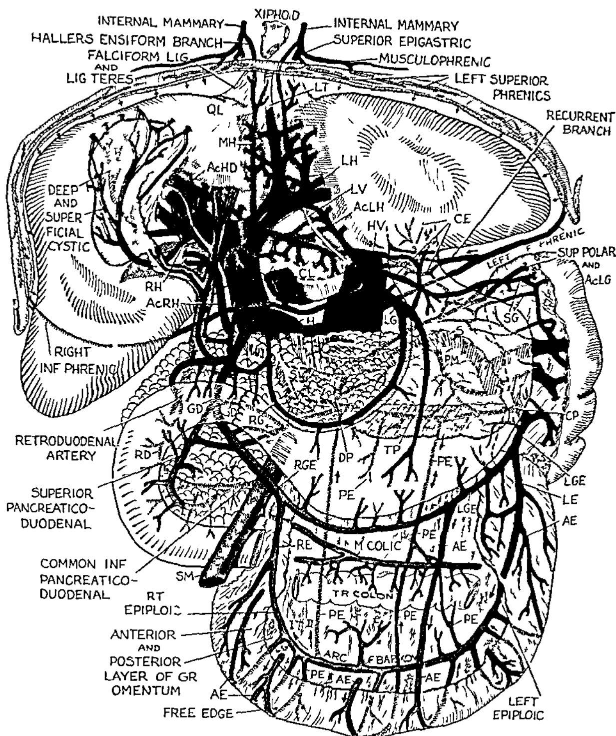


Fig 100 Some of the 26 possible collateral arterial pathways to the liver (based on 200 dissections) The composite drawing was made by the author and Vincent Nast and was published in *Cancer* (6 714 July 1953)

In view of current surgical procedures in the ligation of the hepatic (H) and the splenic (S) arteries for portal cirrhosis (Rienhoff) and the complete removal of the celiac axis in exenteration of the stomach two thirds of the pancreas the spleen the great omentum and the regional lymph nodes for carcinoma of the stomach (Appleby) some of the collateral pathways

(Continued on next page)

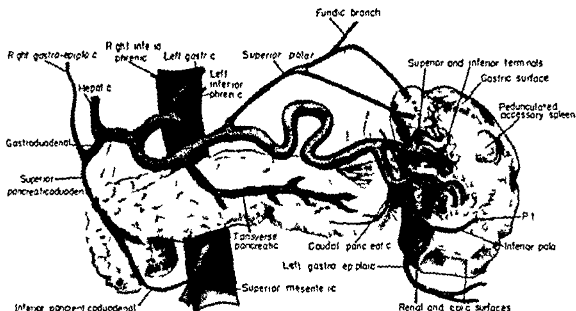


Fig 103 Tetrahedral spleen with a pedunculated accessory spleen The tortuous looped splenic is 17 cm long and has 13 lienal branches the superior polar arising from a short (5 cm) splenic trunk Hepatolienogastric celiac trunk Splenic index 9 (low) Total length of splenic arterial bed 56 cm (W M 82 yrs)

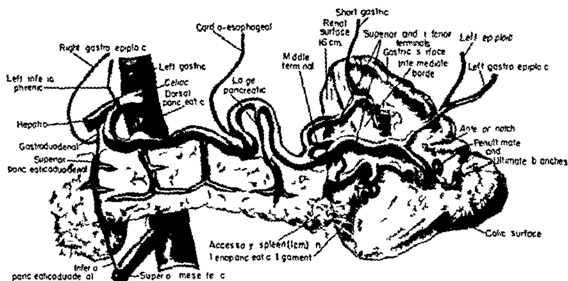


Fig 104 Tetrahedral spleen with a magistral tortuous splenic trunk which courses 16 cm then divides into 3 terminals (9 to 11 cm) that give off a total of 20 lienal branches Hepatolienal celiac trunk left gastric and dorsal pancreatic from aorta Splenic index 33 (very high) Total length of arterial bed 48 cm (M N 82 yrs)

FIG 101 Tetrahedral spleen with 17 lienal branches the polar arteries being distributed selectively to the tubercle and the notched areas The tortuous coiled splenic (15 cm) shows the following segments (1) suprapancreatic (2) pancreatic (3) prepancreatic (4) prehilar Hepatolienogastric celiac trunk with left gastric as first branch (usual) Splenic index 12 (low) Total length of splenic arterial bed (splenic plus its lienal branches) 50 cm (W M 79 yrs)

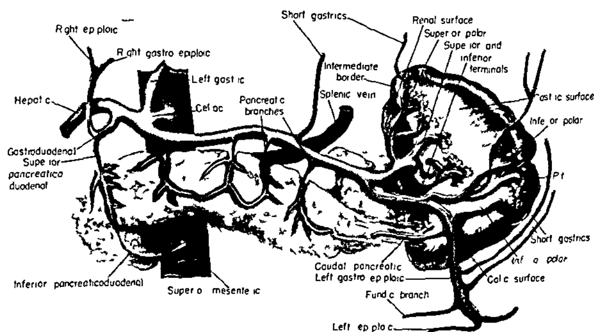
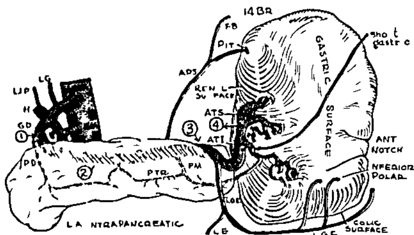


FIG 102 Tetrahedral spleen with distributed vascularization and hilus Inferior polars correspond to notched areas Hepatolienogastric celiac trunk (tripod of Haller) Straight suprapancreatic splenic (11 cm) 14 lienal branches Splenic index 23 Total length of splenic arterial bed 42 cm (M N 42 yrs)

Fig 107 Large tetrahedral spleen Surfaces diaphragmatic 15 x 9 cm gastric 5 cm renal 8 cm colic 6 x 8 cm Split celiac trunk or axis (lieno gastric hepatomesenteric) Intrapancreatic splenic (11 cm long 7 mm wide) Its topographic relations are (1) suprapancreatic (2) pancreatic (3) prepancreatic (4) prehilar Slender superior polar artery (APS) (7 5 cm long) enters a tubercle and 2 small inferior polar arteries from the left gastro epiploic (LGE) enter the notched area 14 lienal branches Low splenic index 15 Total arterial lienal bed length 33 cm (M W 17 yrs)



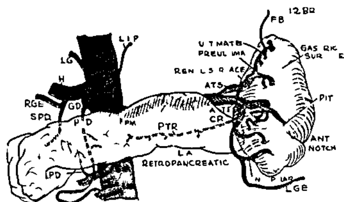
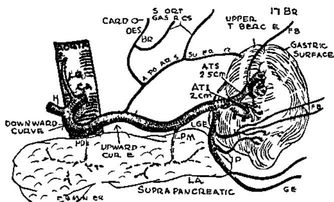


Fig 108 (*Left*) Small spleen characteristically common in the Negro race (Moon 1928) Surfaces diaphragmatic 9 5 x 4 cm thickness 2 5 cm gastric 2 5 cm renal 2 cm Hepatolieno gastric celiac trunk (CA) Retropancreatic magistral splenic (8 cm x 6 5 mm) that divides 3 5 cm from the spleen into a superior terminal (ATS) and an inferior terminal (ATI) branch The dorsal pancreatic (PD) unites with the inferior mesenteric (IM) Lienal branches 12 Splenic index 25 Total lienal arterial bed length of the splenic trunk and its lienal branches 32 cm (M N 72 yrs)

Fig 109 (*Right*) Small spleen Surfaces diaphragmatic 9 x 6 cm thickness 2 cm gastric 3 5 cm renal 2 cm Hepatolienogastric celiac trunk (CA) Upper tubercle (3 cm) supplied by a superior polar artery (APS) (9 cm) Lower pole has 2 inferior polar arteries (IP) from the left gastro epiploic (LGE) Suprapancreatic distributed splenic artery is 9 cm long 7 mm wide Cardio esophageal and short gastric branches from APS 9 cm long Lienal branches 17 Low splenic index 17 Total length of arterial bed of the splenic trunk and its lienal branches 40 cm (M W adult)



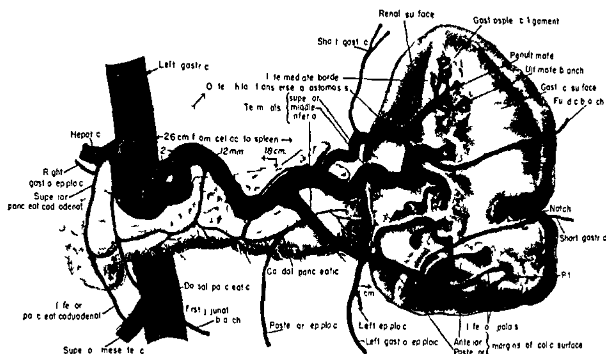


Fig 105 Large tetrahedral spleen with a large extremely long tortuous coiled markedly distributed splenic trunk which is 18 cm the terminals being 7 cm The 22 lienal branches are disposed in 11 frontal planes the inferior polars being selectively distributed to notched areas Segments 2 and 3 are partly intrapancreatic Splenic index 21 Total length of splenic arterial bed 90 cm 3 times that of some individuals (M W 53 yrs)

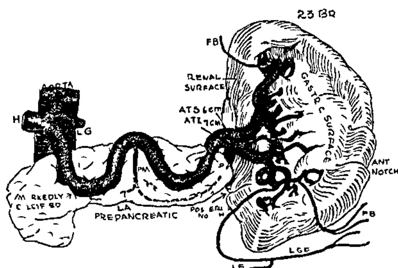


Fig 106 Large orange segmentlike spleen with distributed hilus Surface measurements diaphragmatic 16 x 9 5 cm thickness 3 5 cm gastric 5 cm renal 3 cm Hepatolienogastric celiac trunk (CA) (tripod) Prepancreatic (rare) markedly calcified large and magistral splenic artery 17 cm long 10 mm in diameter its terminal division being 5 cm from the spleen Vertical length of the vessel entrance into the spleen 9 cm planes 6 pits 5 lienal branches 23 Splenic index 27 Total arterial bed length of the splenic trunk and its lienal branches 62 cm (M W 79 yrs)

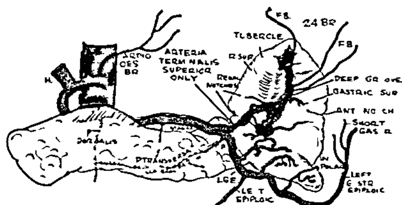


Fig 113 Notched orange segmentlike spleen with an inferior thumblike lobe supplied by 3 inferior polar arteries from the left gastro-epiploic artery Surfaces diaphragmatic 10 x 5.5 cm thickness 2 5 cm gastric 3 cm renal 2 cm Hepatolienogastric celiac trunk Unusual nontortuous sclerotic splenic (11 cm x 7 mm) dividing only into the LGE and the superior terminal (ATS) (6.5 cm) the latter coursing in a deep groove beside a large tubercle (3 cm) Slender cardio-esophageal branch from the celiac artery Double size hepatic (H) (12 mm) Collateral circulation via the dorsal (PD) the transverse (PT) and the caudal (CP) pancreatic. Lienal branches 24 Splenic index 30 Total lienal arterial bed length 36 cm (M N 66 yrs)

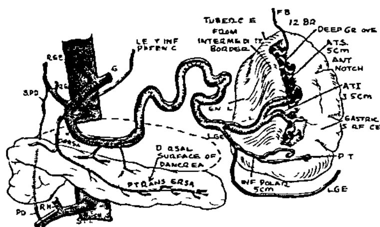


Fig 114 Orange segmentlike spleen with prominent intermediate border (10 mm) tubercle (4 cm) and deep groove Surfaces diaphragmatic 11 x 7.5 cm thickness 3 5 cm gastric 3 5 cm renal 3 cm Lienogastric celiac trunk (CA) with right hepatic (RH) from the superior mesenteric (SM) and the left hepatic (LH) from the left gastric (LG) Long magistral and looped splenic (15 cm x 7 mm) dividing nearly at the hilus of the spleen The pancreas is turned forward to show the course of the transverse pancreatic (PT) on its dorsal inferior surface Lienal branches 12 Splenic index 21 Total lienal arterial bed length 42 cm (M W 55 yrs)

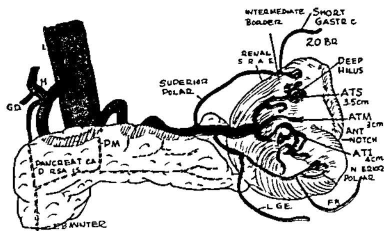


Fig 110 Tetrahedral spleen with prominent intermediate border (6 mm) Surfaces diaphragmatic 8 x 7 cm gastric 4 cm colic 5 5 x 2 5 cm Hepatolienogastropancreatic celiac trunk (CA) 2 left gastrics (LG) Tortuous distributed splenic (12 cm x 8 mm) that distally divides into 3 terminals the third being the arteria terminalis media (ATM) Superior polar 5 cm The left gastro-epiploic (LGE) arises from the S 5 cm from the spleen Lienal branches 20 Splenic index 26 Total arterial bed length of the splenic trunk and its lienal branches 38 cm (M W 78 yrs)

Fig 111 Very large tetrahedral spleen Surfaces diaphragmatic 10 x 8 cm thickness 2 cm gastric 4 cm renal 3 cm colic 5 x 1 5 cm Hepatolienogastric celiac trunk The very long superior polar artery (APS) (10 cm) springs from the first part of the splenic which is looped and coiled being 17 cm long (6 mm wide) to its division into the superior (ATS) and the inferior (ATI) terminals Distributed vascularization the S breaking up early into its branches of which 17 enter the spleen Common origin of the left gastro-epiploic (LGE) and the inferior polar from the ATI Very low splenic index 9 Total lienal arterial bed length 63 cm (M W 70 yrs)

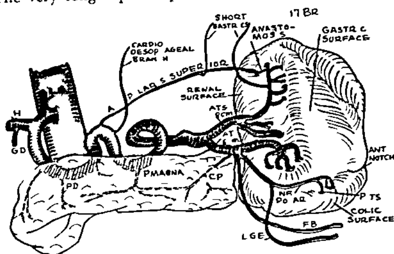
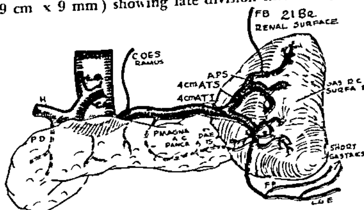


Fig 112 *(Right)* Evenly contoured triangular spleen Surfaces diaphragmatic 9 x 7 cm thickness 2 5 cm gastric 4 cm renal 3 5 cm Hepatolienogastric celiac trunk (CA) Short straight magistral splenic (9 cm x 9 mm) showing late division into its superior (ATS) and inferior (ATI) terminals the latter giving rise to the left gastro-epiploic (LGE) and the caudal pancreatic (ACP) The 21 lienal branches enter the spleen in 10 different planes 5 via the renal surface Collateral circulation via the ACP and the arteria pancreatica magna Splenic index 30 Total length of lienal arterial bed 30 cm (M N adult)



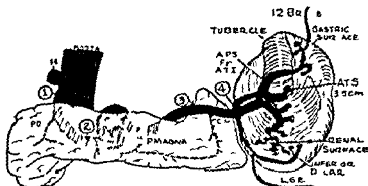


FIG 117 Orange segmentlike spleen with prominent tubercle (3 x 1 5 cm) Surfaces diaphragmatic 9 x 6 cm gastric 3 5 cm renal 1 cm Hepatolienogastric celiac trunk (CA) (tripod) Very long magistral splenic (16 cm x 7 mm) its tortuous part mostly retropancreatic Its topographic relations are (1) suprapancreatic (2) pancreatic (3) prepancreatic (4) prehilar Unusual origin of the superior polar (APS) (4 cm) from the arteria terminalis inferior (ATI) 12 lienal branches of which 3 enter the renal surface Splenic index 30 Total arterial bed length of the S and its lienal branches 43 cm (M N 65 yrs)

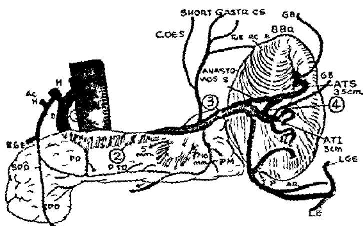


FIG 118 Orange segmentlike spleen with large (2 cm) tubercle Surfaces diaphragmatic 9 5 x 6 5 cm gastric 3 cm renal 3 cm Hepatolienogastric celiac trunk (CA) The splenic artery (12 cm x 7 mm) is partly intrapancreatic and coiled The coil shows distinct differences in the diameter of lumen it being larger proximally (10 mm) than distally (5 mm) Topographic relations of the S are (1) suprapancreatic (2) pancreatic (3) prepancreatic (4) prehilar Only 8 lienal branches one an inferior polar from the left gastro-epiploic (LGE) The superior polar (8 cm) gives off cardio-esophageal (C OES) and short gastric branches Short anastomosis (1 5 cm) between the S and the arteria terminalis superior (ATS) Splenic index 17 Total lienal arterial bed length 35 cm (M W 40 yrs)

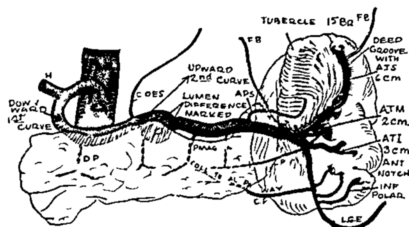


Fig 115 Spleen with very large tubercle (5 x 2 cm) and notched anterior border Hepatolienogastric celiac trunk (CA) Coiled splenic (11 cm x 9 mm) having marked lumen differences breaks up into a distributed type of splenic vascularization Origin of the left gastro epiploic (LGE) at the same point as that of the splenic terminals which comprise an arteria terminalis media (ATM) Small polar artery to the tubercle Early cardio-esophageal ramus Collateral circulation via the caudal pancreatic (CP) and the a pancreatica magna Lienal branches 15 Splenic index 23 Total lienal arterial bed length 39 cm (M W 66 yrs)

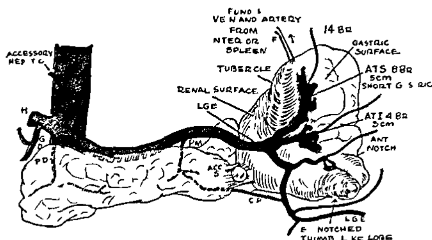


Fig 116 Pea size accessory spleen (1 cm) in lienopancreatic ligament Anterior border of spleen notched with thumblike lobe Prominent tubercle (3 cm) Surfaces diaphragmatic 10 x 7 cm gastric 4 cm renal 3 cm Hepatolienogastric celiac trunk Typical sample of a magistral splenic artery (11 cm x 9 mm) coursing directly toward hilus of spleen before dividing into its terminal branches LGE arises at same point as terminals Fundic artery and vein from interior of spleen a frequent phenomenon Lienal branches 11 High splenic index 33 Total lienal arterial bed length 30 cm (M N 32 yrs)

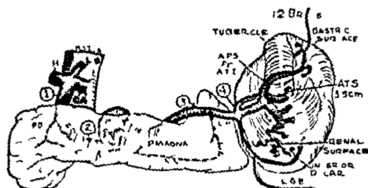


Fig 117 Orange segmentlike spleen with prominent tubercle (3 x 1 5 cm) Surfaces diaphragmatic 9 x 6 cm gastric 3 5 cm renal 1 cm *Hepatolienogastric celiac* trunk (CA) (tripod) Very long magistral splenic (16 cm x 7 mm) *its tortuous part mostly retropancreatic* Its topographic relations are (1) suprapancreatic (2) pancreatic (3) prepancreatic (4) prehilar Unusual origin of the superior polar (APS) (1 cm) from the arteria terminalis inferior (ATI) 12 lienal branches of which 3 enter the renal surface Splenic index 30 Total arterial bed length of the S and its lienal branches 43 cm (M N 63 yrs)

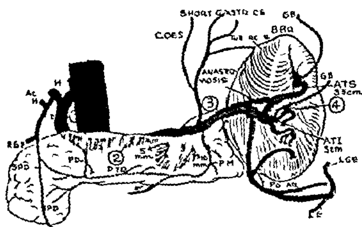


Fig 118 Orange segmentlike spleen with large (2 cm) tubercle Surfaces diaphragmatic 9 5 x 6 5 cm gastric 3 cm renal 3 cm *Hepatolienogastric celiac trunk* (CA) The splenic artery (12 cm x 7 mm) is partly intrapancreatic and coiled The coil shows distinct differences in the diameter of lumen it being larger proximally (10 mm) than distally (5 mm) Topographic relations of the S are (1) suprapancreatic (2) pancreatic (3) prepancreatic (4) prehilar Only 8 lienal branches one an inferior polar from the left gastro-epiploic (LGE) The superior polar (8 cm) gives off cardio-esophageal (COES) and short gastric branches Short anastomosis (1 5 cm) between the S and the arteria terminalis *superior (ATS) Splenic index 17 Total lienal arterial* bed length 35 cm (M W 40 yrs)

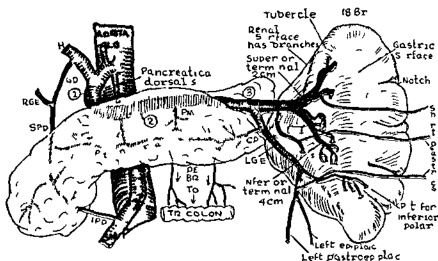


FIG 119 Tetrahedral spleen with markedly notched anterior border Surfaces diaphragmatic 13 x 8 cm gastric 6 5 cm renal 3 cm Hepatolienogastric celiac trunk A straight splenic artery (12 cm x 6 mm) with selective distribution of the lienal branches *to the notched areas* Topographic relations of the S (1) supra pancreatic (2) pancreatic (3) prepancreatic *(4) prehilar The dor*sal pancreatic (PD) from the celiac gives rise to the transverse pancreatic (PT) that supplies the slender posterior epiploic (PE) branches to the transverse colon Collateral circulation via the left gastro epiploic (LGE) the caudal pancreatic (CP) the PT the superior pancreaticoduodenal (SPD) the gastroduodenal (GD) the hepatic (H) and also through the arteria pancreatica dorsalis Lienal branches 18 *Splenic index* 20 Total lienal arterial bed length 43 cm (M adult)

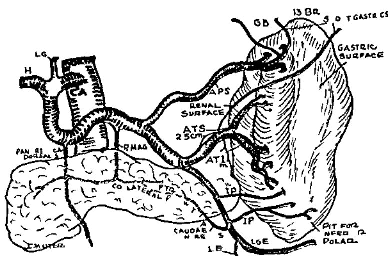


FIG 120 Large orange segmentlike *spleen with* distributed vascularization Surfaces diaphragmatic 12 5 x 7 cm gastric 4 cm renal 2 5 cm Hepatolieno gastric celiac trunk (CA) (tripod) Typical sample of an *early resolution of the* splenic artery (15 cm x 10 mm) into its branches After a course of 8 cm the splenic trunk gives off a large superior polar (APS) (7 cm long) then the left *gastro epiploic* (LGE) that supplies 2 inferior polars (IP) and near *the spleen* divides into superior and inferior terminal branches The lienal branches enter the spleen via 2 hila 7 pits and in 6 different planes Collateral circulation through the caudal pancreatic (CP) *the transverse pancreatic (PT) the* a pancreatica magna (PM) and the a pancreatica dorsalis Latter proceeds caudal to the pancreas to the transverse mesocolon Very low splenic index *16 Total lienal arterial bed length 50 cm* (M W 66 yrs)

Fig 121 Spleen with a double blood supply to it through the splenic (13 cm x 11 mm) and through a transverse pancreatic from the superior mesenteric (SM) it being sufficiently large (15 cm x 5 mm) to constitute an arteria splenica secundaria Surfaces diaphragmatic 10 5 x 7 5 cm gastric 4 cm renal 3 cm Hepatolienogastric celiac trunk (short tripod) Pancreas partly turned to show the course of the transverse pancreatic (PT) along its dorsal inferior border Huge enlargement of the inferior pancreaticoduodenal (IPD) (7 mm wide) *indicating the large amount of blood that may pass through this route when the hepatic (H) is ligated* Lienal branches 15 Splenic index 23 Total lienal arterial bed length 18 cm With addition of the PT the index is 18 and the bed length is 63 cm (M W 80 yrs)

Fig 122 Tetrahedral spleen with highly distributed vascularization Surfaces diaphragmatic 11 x 8 cm gastric 6 cm renal 3 5 cm Celiac trunk (axis) is split into a hepatogastric and a lienomesenteric trunk The splenic artery is very long (18 cm x 9 mm) tortuous coiled and derived from the superior mesenteric (SM) 31 lienal branches enter the spleen in 16 different planes there being 3 splenic terminals The long superior polar (APS) (9 cm x 4 mm) gives off the left inferior phrenic and the short gastric arteries The anterior and the posterior pancreaticoduodenal arcades around the head of the pancreas respectively made by the superior pancreaticoduodenal (SPD) and the retroduodenal (RD) are shown An inferior polar artery gives rise to the left gastro-epiploic (LGE) Low splenic index 8 Total lienal arterial bed length 63 cm (M adult)

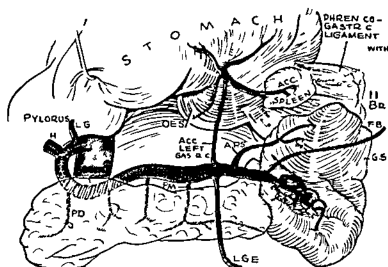


FIG 123 Exceptionally large accessory spleen (3 5 x 2 cm) in the phrenicogastric ligament with its blood supply from an accessory left gastric (AcLG) It represents most probably a severed part of the upper pole of the spleen Surfaces diaphragmatic 10 x 7 cm gastric 3 cm renal 3 5 cm Hepatolienogastric celiac trunk Very early origin of *the left gastro-epiploic (LGE)* from the splenic (12 cm x 6 mm) that has no superior terminal a superior polar (APS) taking its place Distributed vascularization and hilus with 11 lienal branches of which 5 enter the renal surface Splenic index 30 Total arterial bed length of splenic trunk and its lienal branches 30 cm (M W 48 yrs)

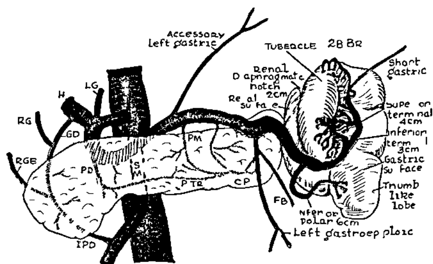


FIG 124 Small irregularly contoured orange segmentlike spleen with deep anterior and posterior notches inferior thumb like lobe and prominent tubercle (3 x 12 cm) Surfaces diaphragmatic 9 x 6 cm gastric 5 cm renal 2 cm Hepatolienogastric celiac trunk A large accessory left gastric (AcLG) from the splenic the latter being 14 cm long and 8 mm wide 28 lienal branches Collateral circulation through the long trans pancreatic route via the caudal pancreatic (CP) the transverse pancreatic (PTr) and the dorsal pancreatic (PD) Splenic index 21 Total length of the splenic arterial bed made by the splenic trunk and its lienal branches 42 cm (M adult)

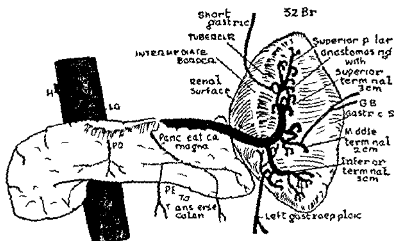


FIG 125 Triangular spleen with even contours intermediate border (12 mm) and tubercle (5 cm) Surfaces diaphragmatic 12 x 9 cm gastric 4 cm renal 3 cm Hepatolienogastric celiac trunk giving off the hepatic (H) as the first branch (infrequent) Straight magistral splenic artery (12 cm x 6 mm) that courses to the hilus before branching 3 splenic terminals that give off 32 lienal branches one of the highest number encountered Posterior epiploic (PE) branches of the transverse pancreatic to the transverse mesocolon Splenic index 26 Total arterial bed length of the splenic trunk and its lienal branches 15 cm (F N adult)

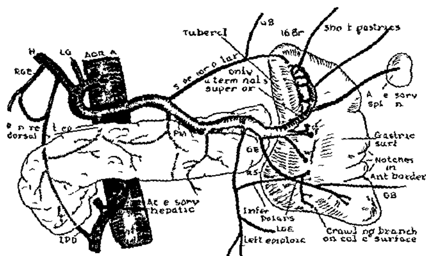


FIG 126 Tetrahedral spleen with tubercle notched anterior border and an accessory spleen in the gastrosplenic ligament Surfaces diaphragmatic 10 x 6 cm gastric 4 cm renal 2 cm Hepatolienogastric celiac trunk (CA) Selective distribution of the lienal branches to notched areas and tubercle Long (9 cm) superior polar (SP) from a splenic (14 cm long 8 mm wide) that ends in only one terminal the arteria terminalis superior (ATS) (6 cm long) 16 lienal branches of which one is a long inferior polar (IP) (6 cm) Splenic index 14 Total lienal arterial bed length 50 cm (M adult)

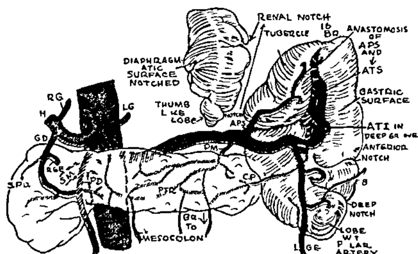


FIG 127 Markedly irregular notched spleen with tubercle (4.5 cm.) and inferior thumblike lobe. A renal notch (1.5 cm. deep) extends over the diaphragmatic surface. Surfaces: diaphragmatic 11 x 6 cm., gastric 4 cm., renal 3.5 cm. Hepatolienogastro pancreatic celiac trunk (CA). *Dorsal pancreatic (PD) to large intestine where it joins the ileocolic.* The splenic (12 cm. x 5 mm.) gives off the superior polar (APS) that anastomoses with the superior terminal (ATS) constituting an outer hilar transversal. 16 lienal branches. Splenic index 22. Total lienal arterial bed length 40 cm. (F. N. 35 yrs.)

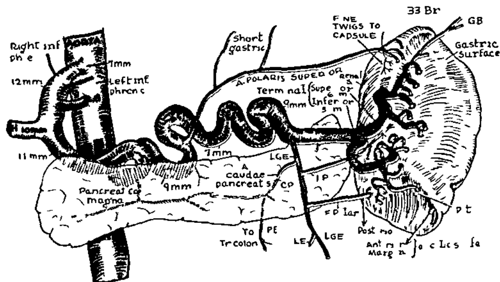


FIG 128 Tetrahedral spleen with an extensive colic impression. Surfaces: diaphragmatic 13 x 7 cm., gastric 4.5 cm., renal 2 cm., colic 5 x 2.5 cm. Hepatolienogastric celiac trunk (axis). The extremely long (32 cm.) tortuous coiled looped and sclerotic splenic artery shows marked differences in diameter (11, 9, 7 mm.) and has the highest number of lienal branches (33) encountered. Notable diameter difference also in the celiac artery (from 7 to 12 mm.). Distributed vascularization and hilus with a long superior polar (APS) (12 cm. x 4 mm.) and branches to the colic and the renal surfaces. Splenic index 15. Total lienal arterial bed length 92 cm., *it being 3 times that of some individuals having only 30 cm.* (M. W. adult.)

Fig 129 Spleen with prominent tubercle (3 cm) and a free accessory spleen (1 cm) near the inferior pole Surfaces diaphragmatic 13 x 11 5 cm gastric 1 cm renal 1 5 cm Hepatolienogastric celiac trunk (CA) (tripod) The splenic (11 cm x 10 mm) is of the magistral type since it proceeds to 2 5 cm from the spleen before dividing into its superior (ATS) and inferior terminal (ATI) branches There is however an early origin of the left gastro-epiploic (LGE) (5 5 cm from the spleen) that supplies 2 short inferior polar arteries one of which supplies the accessory spleen 16 lienal branches Splenic index 20 Total lienal arterial bed length *34 cm as opposed to 92 cm* in Figure 128 (M N adult)

Fig 130 Tetrahedral lobular spleen with deep notches (4 cm deep) on the anterior border that nearly severs the organ into 3 parts Surfaces diaphragmatic 15 x 7 cm gastric 5 cm renal 3 5 cm Hepatolienogastro-pancreatic celiac trunk The unusual splenic artery (18 cm x 8 mm) is markedly long tortuous and coiled *being twice as long as need be* It gives off a long superior polar (APS) (9 cm) that supplies 13 of a total of 36 lienal branches these being disposed in 20 different planes and having 15 pits as points of entrance The left epiploic artery from the left gastro epiploic (LGE) always forms the left limb of the arcus epiploicus magnus in the posterior layer of the great omentum below the transverse colon The dorsal pancreatic (I D) descends to unite with the middle colic The retroduodenal (RD) from the gastroduodenal (GD) Splenic index 8 (lowest seen) Total lienal arterial bed length 86 that of the superior polar (9 cm) alone being 23 cm (M W 52 yrs)

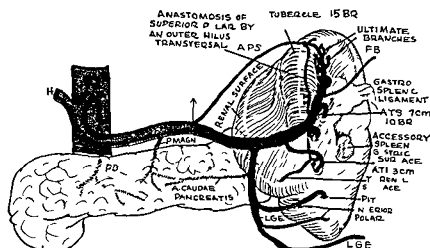


FIG 131 Spleen with a pedunculated (attached) accessory spleen (1 cm) on its gastric surface (lien succenturiatus) Very large tubercle (4 x 2 cm) Surfaces diaphragmatic 11 5 x 7 5 cm gastric 4 5 cm renal 3 5 cm Hepatolienogastric celiac trunk Main blood supply comes from the superior terminal (ATS) a branch of which effects an *outer hilar transverse anastomosis with the superior polar* (APS 9 cm long) Distributed vascularization and hilus Length of vessel entrance 10 cm planes 5 pits 2 The splenic artery (11 cm x 7 mm) is wider than the hepatic (H) a frequent observation 15 lienal branches Low splenic index 11 Total lienal arterial bed *length 51 cm (M N adult)*

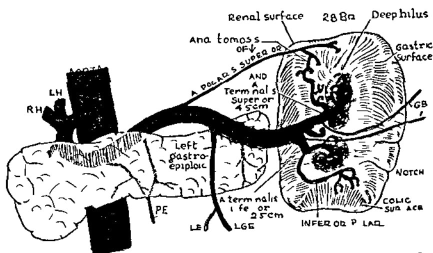


FIG 132 Tetrahedral spleen with 2 deep hila Surfaces diaphragmatic 11 x 7 cm gastric 6 cm renal 2 5 cm colic 5 x 2 cm Hepatolienogastric celiac trunk with LIP The splenic (15 cm x 10 mm) exhibits a *characteristic outer hilar transverse anastomosis between its superior terminal (ATS) and superior polar (APS) branches The latter being long (8 cm) and slender could be missed readily in splenectomies causing fatal postoperative bleeding (Wm Mayo 1915)* Vessel entrance vertical length thereof 9 cm planes 11 pits 11 hila 2 Lienal branches 28 Splenic index 14 Total lienal arterial bed length 50 cm (M adult)

Fig 133 Spleen with a *free per size accessory* spleen (1 cm) in a deep hilar fossa Surfaces diaphragmatic 12 5 x 9 cm gastric 1 cm renal 1 5 cm Large tubercle (9 cm) with the superior polar (APS) (3 cm long) Hepatolienogastriccelrac trunk (axis) Distributed vascularization with a very long (7 cm) inferior polar derived from a left *gastro-epiploic* (LGE) that arises 5 cm from the spleen The splenic artery (11 cm x 6 mm) gives rise to an accessory left gastric —once known as the *ramus esophagogastricus posterior ascendens* Topographic relations of the S (1) suprapancreatic (2) pancreatic (3) prepancreatic (4) prehilar Vessel entrance 10 planes 2 hila 6 pits 22 branches Splenic index 17 Total lienal arterial bed length 17 (M W 11 yrs)

Fig 134 Orange segmentlike spleen with large tubercle (4 x 1 5 cm) Surfaces diaphragmatic 12 x 7 cm gastric 5 cm renal 3 cm Hepatolienogastric celiac trunk Tortuous coiled splenic (14 cm x 9 mm) shows marked differences in lumina (9 7 10 mm) *Outer hilar transverse anastomosis between SP and ST and between ST and IT* Distributed vascularization with 19 lienal branches Typical illustration of the *arcus epiploicus magnus of Barkow in posterior layer of great omentum below transverse colon left limb formed by left epiploic right by anterior epiploic from RGF or PT* Posterior epiploics unite with branches of arcades of MC and with ascending branches of arc Latter *is a collateral pathway for liver stomach and transverse* colon Splenic index 11 Total lienal arterial bed length 50 (M adult)

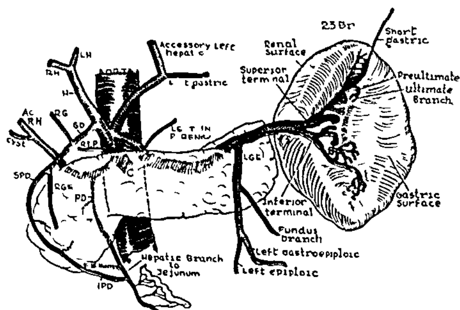


Fig. 135 Tetrahedral spleen with compact hilus and even borders. Surfaces: diaphragmatic 10 × 7 cm, gastric 4 cm, renal 3.5 cm. Hepatolienogastric celiac trunk (C). The magistral splenic artery (12 cm × 6 mm) courses to the hilus before breaking up into its terminal branches. *The dorsal pancreatic (PD) from an accessory right hepatic (AcRH) becomes the first jejunal branch and unites with the inferior pancreaticoduodenal (IPD).* Four hepatic arteries present, the cystic artery being derived from an AcRH. Early origin of the left gastroepiploic (LGE), it being 7 cm from the spleen. 23 lienal branches. Splenic index very high, 35. Total lienal arterial bed length, 31 cm. (M., adult.)

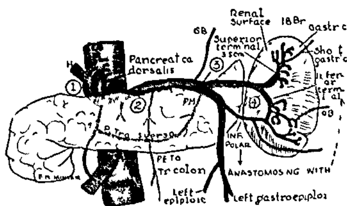


Fig. 136 Very small tetrahedral spleen. Surfaces: diaphragmatic 6 × 4 cm, gastric 3 cm, renal 1.5 cm. Hepatolienogastropancreatic celiac trunk (C). Topographic relations of the splenic (10 cm × 6 mm) are *(1) suprapancreatic, (2) pancreatic, (3) prepancreatic, (4) prehilar.* Its inferior terminal (IT) forms a loop with the inferior polar from the LGE. The dorsal pancreatic (PD) from the celiac (C), after giving off the transverse pancreatic (PT), unites with the superior mesenteric (SM), effecting a collateral route between the CA and the SM. Collateral circulation also possible through the PD, the PT and the a. pancreatica magna (PM). Lienal branches 18. Splenic index *23. Total* lienal arterial bed length 30 cm. (M., adult.)

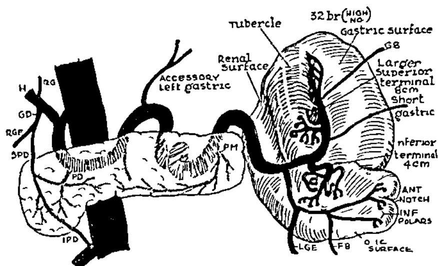
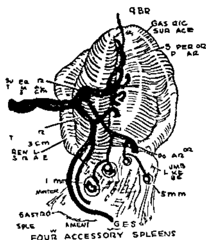
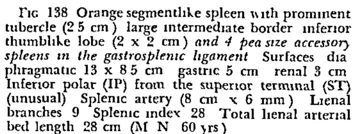


Fig 137 Large tetrahedral spleen with prominent tubercle and large inferior thumblike lobe Surfaces diaphragmatic 15 x 9 cm gastric 6 5 cm renal 3 5 cm colic 6 x 1 5 cm Hepatolienogastric celiac trunk (C) The splenic is twice as long (22 cm x 8 mm) *as it need be* and is markedly tortuous a coiled section being embedded deeply in the pancreas Selective distribution of the inferior polar arteries to the notched areas the left gastro-epiploic (LGE) arising from the IL Lienal branches 32 (unusually high number) Splenic index 23 *Total lienal arterial bed length 72 cm as opposed to some individuals having only 30 cm* (M adult)




Fig 138 Orange segmentlike spleen with prominent tubercle (2 5 cm) large intermediate border inferior thumblike lobe (2 x 2 cm) *and 4 pea size accessory spleens in the gastrosplenic ligament* Surfaces diaphragmatic 13 x 8 5 cm gastric 5 cm renal 3 cm Inferior polar (IP) from the superior terminal (ST) (unusual) Splenic artery (8 cm x 6 mm) Lienal branches 9 Splenic index 28 Total lienal arterial bed length 28 cm (M N 60 yrs)

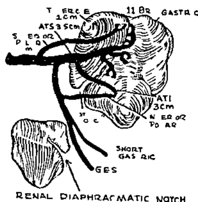


Fig 139 Triangular spleen nearly cleft in two by a deep renal diaphragmatic notch Surfaces diaphragmatic 10 x 5 cm gastric 3 cm renal 2 cm Splenic artery (10 cm x 6 mm) 11 lienal branches Splenic index 24 Total lienal arterial bed length 33 cm (M N 41 yrs)

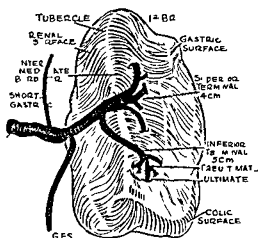


Fig 140 Large tetrahedral spleen with prominent tubercle (5 cm) intermediate border (11 mm) and compact double hilus Surfaces diaphragmatic 15 x 8 5 cm gastric 4 cm renal 3 cm colic 5 x 2 cm Magistral splenic artery (18 cm x 9 mm) Lienal branches 10 *Splenic index very high 50 the highest noted* Total lienal arterial bed length 36 cm (M N adult)

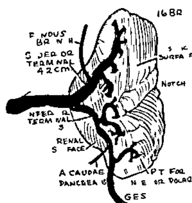


Fig 141 Orange segmentlike spleen with distributed hilus Surfaces diaphragmatic 12 x 6 cm gastric 2 5 cm renal 2 cm Magistral splenic artery (8 cm x 6 mm) Lienal branches 16 Splenic index 26 Total lienal arterial bed length 30 cm (M N 35 yrs)

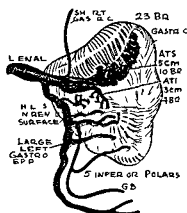


Fig 142 Small triangular spleen with a hilus on the renal surface Surfaces diaphragmatic 8 x 7 cm gastric 5 cm renal 2 cm *The splenic blood supply from the left gastro epiploic (LGE) is considerable 9 of the 23 lienal branches being derived from it* Splenic artery (10 cm x 7 mm) Splenic index 18 Total lienal arterial bed length 18 cm (M W 47 yrs)

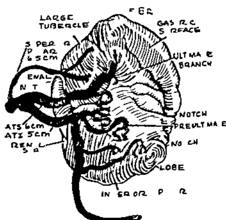


Fig 143 Orange segmentlike spleen with large tubercle (5 cm) and renal notch Surfaces diaphragmatic 13 5 x 9 5 cm gastric 5 cm renal 3 5 cm Selective distribution of the polar arteries to the tubercle and the notched areas Deep renal notch Splenic (10 x 8 mm) Lienal branches 15 Splenic index 16 Total lienal arterial bed length 13 cm (M W 59 yrs)

Fig 144 Orange-segmentlike spleen with posterior notch that bisects the renal surface completely and cuts one half of the diaphragmatic surface (10 x 6 mm) Gastric surface 3 5 cm renal 2 5 cm Magistral splenic artery (11 cm x 6 mm) with 3 terminals ending in 11 lienal branches Splenic index 33 Total lienal arterial bed length 33 cm (M N adult)

Fig 145 Triangular spleen with tubercle (2.5 cm) notched anterior border and distributed vascularization a large blood supply coming from the left gastro-epiploic (LGE) via 3 inferior polars Surfaces diaphragmatic 14 x 7 5 cm gastric 3 5 cm renal 2 5 cm Splenic artery (13 cm x 8 mm) Splenic index 22 Total lienal arterial bed length 40 cm (M W 39 yrs)

Fig 146 Orange-segment like spleen with large tubercle Surfaces diaphragmatic 11 5 x 5 5 cm gastric 3 5 cm renal 2 5 cm *Incomplete double splenic artery (a splenica secunda)* The splenic artery (12 cm x 6 mm) is split for 3 cm Actually it is an early origin of a long superior polar (APS) which in its course remains anastomosed with the S (remnant of embryologic condition) Lienal branches 6 Splenic index 16 Total lienal arterial bed length 30 cm (M W 80 yrs)

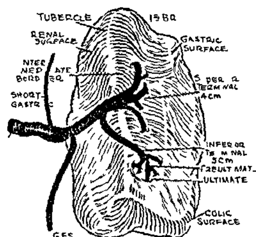


Fig 140 Large tetrahedral spleen with prominent tubercle (5 cm) intermediate border (11 mm) and compact double hilus Surfaces diaphragmatic 15 x 8 5 cm gastric 4 cm renal 3 cm colic 5 x 2 cm Magistral splenic artery (18 cm x 9 mm) Lienal branches 10 *Splenic index very high 50 the highest noted* Total lienal arterial bed length 36 cm (M N adult)

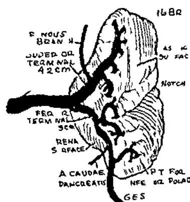


Fig 141 Orange segmentlike spleen with distributed hilus Surfaces diaphragmatic 12 x 6 cm gastric 2 5 cm renal 2 cm Magistral splenic artery (8 cm x 6 mm) Lienal branches 16 Splenic index 26 Total lienal arterial bed length 30 cm (M N 35 yrs)

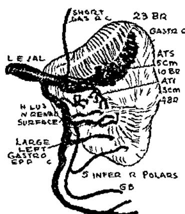


Fig 142 Small triangular spleen with a hilus on the renal surface Surfaces diaphragmatic 8 x 7 cm gastric 5 cm renal 2 cm *The splenic blood supply from the left gastro epiploic (LGE) is considerable 9 of the 23 lienal branches being derived from it* Splenic artery (10 cm x 7 mm) Splenic index 18 Total lienal arterial bed length 48 cm (M W 17 yrs)

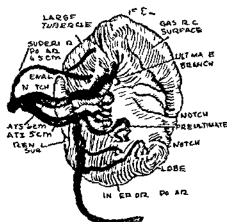
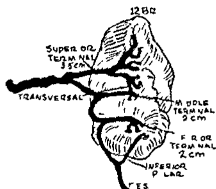


Fig 143 Orange segmentlike spleen with large tubercle (5 cm) and renal notch Surfaces diaphragmatic 13 5 x 9 5 cm gastric 5 cm renal 3 5 cm Selective distribution of the polar arteries to the tubercle and the notched areas Deep renal notch Splenic (10 x 8 mm) Lienal branches 15 Splenic index 16 Total lienal arterial bed length 13 cm (M W 59 yrs)

Fig 150 Tetrahedral spleen with 3 terminal arteries in outer hilar transversal uniting the superior terminal (ST) with the middle terminal Splenic artery (12 cm x 5 mm) Lienal branches 12 Splenic index 32 Total lienal arterial bed length 37 cm (M W 52 yrs)



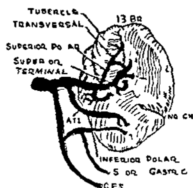


Fig 151 Orange segmentlike spleen with prominent tubercle (3 cm) shown, outer hilar transverse anastomosis (collateral) between the superior polar (SP) and the superior terminal (ST) Splenic artery 11.5 cm Lienal branches 13 Splenic index 28 Total lienal arterial bed length 35 cm (M N 48 yrs)

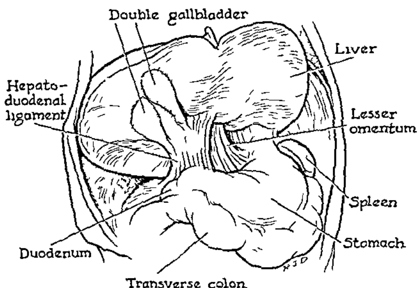


Fig 152 Double gallbladder (GB) found in a male infant (Negro) The 2 GB are separated completely and covered by a common serosa From each vesicle a short cystic duct emerges but from the undissected specimen it cannot be determined whether the CD join to form a Y shaped common CD or join the common bile duct (CBD) separately

FIG 147 Tetrahedral spleen with large tubercle (5 x 3 cm) Surfaces diaphragmatic 11 x 8 cm gastric 3 5 cm renal 2 5 cm colic 3 x 3 5 cm *Complete arteria lienalis secunda (2 cases in 100) Actually the smaller splenic artery II (10 cm x 3 mm) is a superior polar artery (APS) that took origin directly from the celiac (CA)* The larger S (9 cm x 7 mm) shows a selective distribution of its branches to the tubercle and the notched areas Lienal branches 21 Splenic index 17 for splenic I but 13 for splenic I plus II Total lienal arterial bed length 40 cm for I 52 for I plus II (M W adult)

FIG 148 Orange segmentlike spleen with notched anterior border Diaphragmatic surface 15 x 10 cm Typical illustration of outer hilar transverse anastomosis between the superior (ST) and the inferior (IT) terminals *these being the last communications between the major lienal branches for inside the spleen none is present* Splenic artery (15 cm x 10 mm) Lienal branches 13 Splenic index 27 Total lienal arterial bed length 40 cm (M N adult)

FIG 149 Orange segmentlike spleen showing outer hilar *collateral transversal anastomosis* between the inferior terminal (ATI) and the inferior polar The splenic artery is 12 cm long Lienal branches 12 Splenic index 17 Total lienal arterial bed length 40 cm (M N adult)

practically no remnant thereof a repair of the bile passageways can be made effectively by intrahepatic cholangiojejunostomy with partial hepatectomy as accomplished by Longmire and Sanford (1948) and by Wilson and Gillespie (1948) In this difficult operative procedure a knowledge of the constitution and the topographic relations of the hepatic ducts close to the porta hepatis will be very helpful

3 Partial hepatectomy With the development of modern surgical technic partial hepatectomies and hepatic lobectomies are being performed with daily increasing frequency for the removal of angiomas (most frequent in the liver) solitary benign neoplasms and cancerous growths Brunschwig of the Memorial Center for Cancer New York reported in 1953 on a series of 33 patients who had received partial hepatectomy ranging in magnitude from removal of the right or the left lobe to excision of small metastases Among the many early reports on the regeneration of the liver after partial removal are those of von Meister (1894) and Fishback (1929) Because of the extensive vascularization of the liver the major problem in resections and transections of liver tissue is the prevention of hemostasis (hemorrhage) Pickerel and Clay of Durham and Baltimore (1944) maintained that left lobectomy is preferable to partial excision In 3 patients they found that total lobectomy can be effected without functional impairment through a line of cleavage (insertion of the round ligament) that is relatively avascular and has greater capacity for holding sutures The illustrations of Schroy should be of considerable informative value in the removal of angiomas metastases resections including partial or total lobectomy for they afford a clear cut demonstration of the extrahepatic course and the distribution of the main bile ducts thereby serving as a guide for the intrahepatic routes taken by the ducts

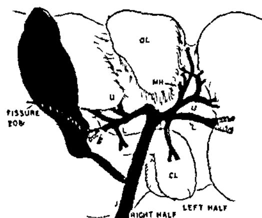


FIG 151 A common type in which the right and the left hepatic ducts (HD) join high in the porta hepatis at right angles i e without the formation of a Y shaped fork Hereby the commencement of the HD is brought into direct contact with the liver a point to be noted in bile duct repair and in liver resections Mode of duct arrangement favors the bilateral character of the biliary tree this being indicated by the dotted line

Middle hepatic duct (MH) from the quadrate lobe drains into the upper (anterior) division of the left hepatic duct As judged from the casts of Healey and Schroy this upper branch (U) represents the inferior area duct of the lateral segment of the left lobe the lower branch (L) representing the superior area duct

Typical manner in which the fissured area below the gallbladder is drained by the lower (posterior) division of the right hepatic duct As judged from casts this duct (L) represents the posterior segmental duct of the right lobe the one above it (U) being the anterior segmental duct Upon unnecessarily deep probing (3–6 mm) in the search for the cystic artery the posterior segmental duct ordinarily well covered by omental tissue readily could be injured causing a postoperative leakage of bile of unknown origin with resultant peritonitis

Drainage of the caudate lobe (CL) is effected by both the right and the left HD the pattern being similar as in Fig 153 HD 2 cm CD 2 cm

The Extrahepatic Bile Ducts As Seen in Extrahepatic Dissections

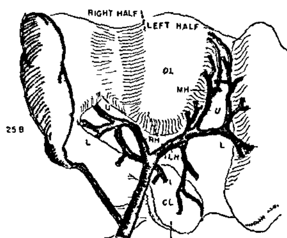


FIG 153 Typical pattern of the formation of the common hepatic duct by the confluence of the right (RH) and the left (LH) hepatic ducts Union of the 2 ducts *in the* porta hepatis is low constituting a Y shaped fork The bilateral character of the biliary tree is indicated by the dotted line which "as *stated* by Schroy *cuts* through the papillary process of the caudate lobe and courses upward to the right *of the quadrate* lobe *through the* gall bladder bed"

The right hepatic duct (RH) divides into an upper (U) and a lower (L) branch which according to subsequent investigations of Healey and Schroy on the intra hepatic biliary tree in plastic casts are purportedly the anterior and the posterior segmental ducts for the anterior and the posterior segments of the right lobe The left hepatic duct (LH) divides into an upper (U) *and a lower (L) branch which* is judged from the casts of Healey and Schroy represent the inferior *and the superior* area ducts of the lateral segment of the left lobe (ducts are depicted in the reverse position as the visceral surface of the liver is shown)

The caudate lobe (CL) is drained by both the right and the left HD A branch from the left side of the papillary process joins the left HD a branch from the right side of the papillary process and the caudate process joins the right HD This pattern is in agreement with the prevailing *type observed by* Healey and Schroy in casts

A total of 25 terminal tributaries to the extrahepatic biliary tree emerge from the liver HD 5 cm CD 6 cm

In order to have a means whereby the anatomist and the surgeon may obtain readily at least an over all concept of the variational anatomy of the extrahepatic bile ducts in particular the mode of formation of the common hepatic duct and its union with the cystic duct the following *illustrations of Paul C Schroy are included* in this atlas The informative value of these illustrations becomes apparent when one realizes that *comparable figures are not to be found in any text of anatomy or surgery* Yet a fundamental familiarity with existent anatomic variations of extrahepatic bile ducts particularly at the porta hepatis is a highly desirable asset to the surgeon Such knowledge will aid him to identify accurately variant positions and structures of bile ducts and thereby help him considerably to avoid injuring them when operating

Aside from their academic interest as a part of *the ever growing* science of anatomy Schroy's illustrations have been included in this atlas because of their import in the following surgical procedures

1 **Routine cholecystectomy** In the varied performance of this dangerous (Lahey) operation far too many injuries to the bile ducts have been made in recent years as emphasized by Lahey Cole Ravdin Walters and Philipp Thorek Behrend Gordon Taylor Gray Appleby Flint Moynihan and many others

2 **In repair operations of the biliary duct system** When the common bile duct has been cut inadvertently leaving

Figures 153 to 161 are from "The Hepatic Duct and the Varied Patterns of Its Extrahepatic Tributaries" by Paul C Schroy (Jefferson Medical College 1951 unpublished) This work was based on dissections of 50 human livers Quotations in the legends are taken directly from Schroy's M S thesis

practically no remnant thereof, a repair of the bile passageways can be made effectively by intrahepatic cholangiojejunostomy with partial hepatectomy as accomplished by Longmire and Sanford (1948) and by Wilson and Gillespie (1948). In this difficult operative procedure a knowledge of the constitution and the topographic relations of the hepatic ducts close to the porta hepatis will be very helpful.

3. Partial hepatectomy. With the development of modern surgical technic, partial hepatectomies and hepatic lobectomies are being performed with daily increasing frequency for the removal of angiomas (most frequent in the liver), solitary benign neoplasms and cancerous growths. Brunschwig of the Memorial Center for Cancer, New York, reported in 1953 on a series of 33 patients who had received partial hepatectomy ranging in magnitude from removal of the right or the left lobe to excision of small metastases. Among the many early reports on the regeneration of the liver after partial removal are those of von Meister (1894) and Fishback (1929). Because of the extensive vascularization of the liver, the major problem in resections and transections of liver tissue is the prevention of hemostasis (hemorrhage). Pickerel and Clay of Durham and Baltimore (1944) maintained that left lobectomy is preferable to partial excision. In 3 patients they found that total lobectomy can be effected without functional impairment through a line of cleavage (insertion of the round ligament) that is relatively avascular and has greater capacity for holding sutures. The illustrations of Schroy should be of considerable informative value in the removal of angiomas, metastases, resections including partial or total lobectomy, for they afford a clear-cut demonstration of the extrahepatic course and the distribution of the main bile ducts, thereby serving as a guide for the intrahepatic routes taken by the ducts.

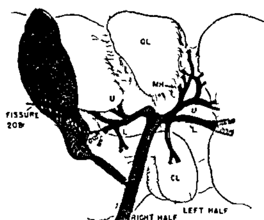


Fig. 154. A common type in which the right and the left hepatic ducts (HD) join high in the porta hepatis at right angles, i.e., without the formation of a Y-shaped fork. Hereby the commencement of the HD is brought into direct contact with the liver, a point to be noted in bile duct repair and in liver resections. Mode of duct arrangement favors the bilateral character of the biliary tree, this being indicated by the dotted line.

Middle hepatic duct (MH) from the quadrate lobe drains into the upper (anterior) division of the left hepatic duct. As judged from the casts of Healey and Schroy, this upper branch (U) represents the inferior area duct of the lateral segment of the left lobe, the lower branch (L) representing the superior area duct.

Typical manner in which the fissured area below the gallbladder is drained by the lower (posterior) division of the right hepatic duct. As judged from casts, this duct (L) represents the posterior segmental duct of the right lobe, the one above it (U) being the anterior segmental duct. Upon unnecessarily deep probing (3-6 mm.) in the search for the cystic artery, the posterior segmental duct, ordinarily well covered by omental tissue, readily could be injured, causing a postoperative leakage of bile of unknown origin with resultant peritonitis.

Drainage of the caudate lobe (CL) is effected by both the right and the left HD, the pattern being similar as in Fig. 153. HD 2 cm., CD 2 cm.

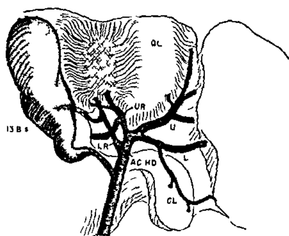


Fig 155 Pattern with 2 main right hepatic branches of which the lower has the features of an accessory hepatic duct As judged from the casts of Healey and Schroy the extra right hepatic duct (LR) represents an instance in which an anterior segmental area duct of the anterior segment of the right lobe joined the hepatic duct outside the liver thereby making it an aberrantly *placed right hepatic duct previously* termed an accessory right hepatic duct (AcHD) Coursing in the cystic triangle of Calot it could have been injured readily in a cholecystectomy Braun of Dresden Germany reported a case in which at operation a comparable lower duct (LR) ended cranially in a blind sac (2 cm long) i e double gallbladder filled with bile that was hidden under a layer of dense connective tissue (Zentralb Chir 53 1055 1926)

The trunk of the left hepatic duct is very short since it divides nearly immediately into an upper (U) and a lower (L) branch these as judged from casts being the inferior and the superior area ducts of the lateral segment of the left lobe *Note that* the division of the left hepatic duct is effected to the right of the umbilical fossa as is frequently the case The upper division (U) of the left hepatic duct (i e inferior area branch of the lateral segment of the left lobe) receives the middle hepatic duct draining the quadrate lobe (QL) or the medial segment of the left lobe the lower division (L) receives a tributary draining the caudate lobe HD 3 cm CD 1 5 cm

In the surgical literature it has been emphasized repeatedly that among the most frequent injuries to the biliary system are *benign strictures of the common* duct caused by clamping or sutures traumatic injury to the hepatic duct in a search for the cystic artery and the cutting or the tearing of an accessory hepatic duct with resultant postoperative recurrent attacks of jaundice and fever

To avoid injury to the bile ducts the variants in the mode of the formation of the common hepatic duct merit special consideration for as stated by the late Dr Lahey, of Boston (1948) *it is on this* duct that most injuries are made *If a* bile duct is injured *it is not the common duct in most cases it is the hepatic the high hepatic that is injured*

Anatomically considered it is extremely difficult in many instances to define the constitution of a common hepatic duct since as illustrated in the drawings it is not always formed by the union of a single right and a single left hepatic duct *The common hepatic duct* may have 2 main right hepatic branches or conversely 2 main left hepatic branches of equal size (Figs 155 156) To designate the lower large branch in the depicted cases as an accessory hepatic duct as has been done in the past is purely an arbitrary categorization for the lower duct is in no way an accessory or an additive one but represents an instance in which one of the segmental ducts of the liver joined the hepatic duct late i e at a lower position *De facto* then it represents only an aberrantly placed branch of the common duct a phenomenon demonstrable roentgenographically (as shown by the Hjortsjo school of Sweden) and one that should be known by every biliary surgeon

A further fundamental item in anatomicosurgical instruction is the existence and the variational anatomy of the middle hepatic duct (medial segmental

duct of Healey and Schroy) Its neglected descriptive illustration in texts of anatomy and surgery is as deplorable as is that regarding the unmentioned middle hepatic artery known since the time of Haller (1756) as the *arteria hepatica media* from which in some instances the entire cystic artery or its superficial branch may arise as shown in this atlas

From the drawings of Schroy which accompany this text it is evident that the topographic relations of the middle hepatic duct are comparable with those of the middle hepatic artery its tributaries from the quadrate lobe being similar in distribution and number to the branches supplied to this lobe by the middle hepatic artery While the middle hepatic artery may be a branch of the right or the left hepatic (in equal proportion [45%] in about 90%) of the gastroduodenal of the right gastric or of the celiac itself the middle hepatic duct is predominantly a branch of the left hepatic duct As shown by Schroy in his M S thesis the middle hepatic duct in 70 per cent of the cases drained into the left hepatic duct before the latter crossed the umbilical fossa and divided into its terminal upper (anterior) and lower (posterior) branches In the subsequent intrahepatic study by Healey and Schroy these branches were termed the inferior and the superior area branches of the lateral segment of the left lobe In 23 per cent the middle hepatic duct drained into the upper division of the left hepatic duct these being cases in which the left hepatic duct divided early into its terminal branches (Fig 161)

Surgically considered *it is important to note that the first left branch of the common hepatic duct is not always the duct draining the left lobe for it may be the middle hepatic duct draining the quadrate lobe* the duct then crossing the left hepatic duct to join the common hepatic duct (Fig 157)

As depicted in the drawings of Schroy

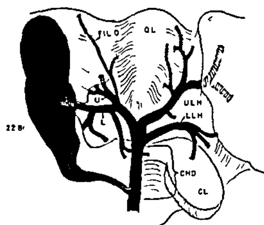


Fig 156 Pattern with 2 main left hepatic ducts the lower (posterior) of which is definitely the so called accessory left hepatic duct It drains part of the caudate lobe part of the left lobe and the area underlying the ductus venosus Two middle hepatic ducts draining the quadrate lobe join the upper left hepatic duct (ULH)

As judged from the casts of Healey and Schroy this specimen represents a case in which the inferior (ULH) and the superior (LLH) area ducts of the lateral segment of the left lobe did not unite to form a single left hepatic duct but joined the common hepatic duct (CHD) separately the distance between the 2 being 5 mm The case disproves the statement sometimes made in the literature and in textbooks that *accessory LEFT* hepatic ducts do not occur

The right hepatic duct divides into an upper (U) i e anterior segmental and a lower (L) i e posterior purported segmental duct for the respective anterior and posterior segments of the right lobe A filamentous duct (Fil D) known as the subvesicular duct courses in the gallbladder bed and drains into the right hepatic duct Resembling a nerve fiber or a connective tissue strand it readily could be injured or torn in the removal of the gallbladder causing postoperative jaundice of unknown origin and peritonitis

Drainage of the caudate lobe (CL) is typical the papillary process being drained by a branch from the left hepatic duct the caudate process by a branch of the posterior segmental duct of the right lobe The cystic duct spirals posteriorly HD 5 5 cm CD 6 cm

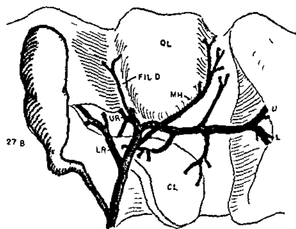


FIG 157 Pattern with 2 main right hepatic ducts the upper (anterior) receives a short filamentous bile duct from the gall bladder bed *As judged from casts the* anterior (UR) and the posterior (LR) segmental ducts of the right lobe did not unite to form a common right hepatic trunk but joined the hepatic duct separately in the porta hepatis *the distance between them* being 15 mm

The long left hepatic duct joins the (UR) anterior segmental branch of the right hepatic duct to the right of the umbilical fossa and is crossed by the middle hepatic duct (MH) which here drains into the common hepatic duct In operative resections of the liver it should accordingly be noted that the first left branch of the common hepatic duct need not necessarily be the left hepatic duct more precisely the left segmental duct

The entire caudate lobe (CL) is drained by the left hepatic duct one branch draining the papillary process the other the caudate process The left hepatic duct receives a bile duct from the umbilical fossa before dividing into its 2 terminal (U and L) branches these purportedly being the inferior and the superior area ducts of the lateral segment of the left lobe as judged from casts (Position of these arteries here is reversed as the visceral surface of the liver is shown)

There are 27 terminal bile ducts leaving the liver In number and in distribution these are fully comparable with the terminal arteries entering the liver as seen in this atlas Angular *union of cystic duct* with hepatic duct HD 3 5 cm CD 3 5 cm

the middle hepatic duct receives from 2 to 5 ducts from the base and the left side of the quadrate lobe *and in over* one half of the cases (56%) one or more ducts from the left lobe (Fig 159) In contrast with the numerous extrahepatic anastomoses which the author found to exist between the branches of the middle hepatic and the left hepatic arteries in the umbilical fossa Schroy found only one instance in which terminal branches of the middle and the left hepatic ducts were anastomosed (Fig 153) In a subsequent study of intrahepatic bile ducts rendered visible in plastic casts Healey and Schroy (1953) were unable to find any evidence of *anastomosis between the biliary ducts in* any of the lobes

*Regarding the caudate lobe it is in*teresting to note that in his study of the extrahepatic bile ducts filled with an injected plastic compound Schroy noted that the bile ducts emerging from the caudate lobe were comparable in number and distribution with the arteries which the author found entering this lobe which are depicted in this atlas In about one half of his specimens Schroy found the caudate lobe to be drained by 2 routes *one or more ducts joining the* left hepatic duct and one or more join*ing the right hepatic duct* (Figs 153 154) The most common and typical pattern was the one in which a branch of the left hepatic drained the papillary process and a branch of the right hepatic drained the caudate process passing behind the hepatic duct (Fig 153)

In regard to the caudate branch from the right hepatic duct Schroy found that *it occurred in 31 cases (62%)* and was usually accompanied by an artery springing from the right hepatic artery and following a similar course It received bile from both the caudate process and the papillary process in 12 cases (Fig 153) in 10 cases it drained only the caudate process (Fig *156) and*

in 9 cases only the papillary process In the region of the caudate lobe Schroy in 2 instances observed clear cut and extensive anastomoses between the branches of the right and the left hepatic ducts which drain the caudate lobe (Figs 163 164) This anatomic arrangement of bile ducts is accordingly different from that with arteries which in the caudate lobe region very frequently exhibit extrahepatic anastomoses between branches of the right and the left hepatic arteries as repeatedly illustrated in this atlas

Subvesicular Bile Duct An anatomic item of surgical import noted by Schroy in his dissections of extrahepatic bile ducts filled with a vinyl acetate compound is the frequent occurrence of a filamentlike subvesicular bile duct (Figs 156 160 162–164) portrayed in many of the author s drawings Schroy stated that the subvesicular duct prevailingly courses to the right side of the gallbladder bed firmly adherent to the latter by numerous twigs In 12 cases of our 50 specimens it drained into the upper (anterior) division of the right hepatic duct (Fig 160) in 6 cases into the right trunk of the common hepatic duct (Fig 162) in 3 cases into the common hepatic duct (Fig 159) and in 2 cases into the lower (posterior) division of the hepatic duct In cholecystectomies it should always be looked for to avoid disconcerting postoperative jaundice The possibility of its occurrence justifies fully a very careful removal of the gallbladder and a postoperative drainage in each case The anatomy of the subvesicular duct as ascertained by Healey and Schroy in their study of the intrahepatic biliary tree in plastic casts is discussed fully in Chapter 7

Regarding the point of union of the right and the left hepatic ducts to form the common hepatic duct at the porta hepatis Schroy noted that the union may be low (Fig 153) intermediate or

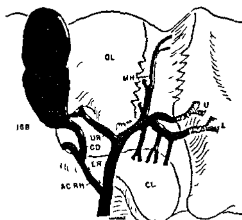


Fig 158 Pattern with 2 main right hepatic ducts the cystic duct draining into the lower (posterior) right hepatic duct instead of opening into the common hepatic duct This pattern is a precarious one and should be known to every surgeon It demonstrates clearly that before a ligature is applied to the cystic duct the latter s relational anatomy should first be inspected and carefully checked as regards its junction point Here the *cystic duct (CD)* drains into one of the main segmental ducts (LR) of the right lobe purportedly the posterior segmental duct which instead of uniting with the anterior segmental duct of the right lobe (UR) joined the common hepatic duct separately constituting a so called accessory hepatic duct (AcHD) It is obvious that the term accessory right hepatic duct is misleading and incorrect for the duct depicted as such constitutes but an aberrantly placed (low) right hepatic branch draining the posterior segment of the right lobe Developmentally considered the pattern illustrated came into being by the fact that the gallbladder bud had its outgrowth from the lower i e purported posterior segment duct of the right lobe

The middle hepatic duct (MH) draining bile from the quadrate lobe (medial segment of the left lobe) joins the left hepatic duct shortly before the latter divides into its terminal inferior (U) and superior (L) area branch of the lateral segment of the left lobe The caudate lobe (CL) is drained by 3 bile ducts which join the left hepatic duct and its superior area branch HD 2 5 cm CD 1 5 cm

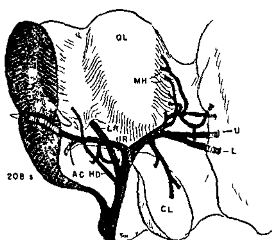


Fig 159 Pattern with 2 main right hepatic ducts with a filamentlike accessory duct joining the common hepatic duct As judged from casts of the intrahepatic biliary tree the anterior segmental duct (LR) joined the hepatic duct separately at a low hilar position and oddly so it being the first branch The right hepatic duct (UR) entering the fissured area under the gallbladder is the purported posterior segmental duct of the posterior segment of the right lobe It is crossed by the anterior segmental duct and by an accessory hepatic duct (AcHD) which coming from the gallbladder bed descends into the confines of the cystic triangle of Calot where it could have been subject to surgical harm in a cholecystectomy with resultant postoperative leakage of bile and peritonitis

The left hepatic duct receives the middle hepatic duct (MH) which in addition to draining the quadrate lobe (medial segment) receives small tributaries from the lateral segment of the left lobe The left hepatic duct divides into its typical terminal branches (U L) these representing the purported inferior and superior area ducts of the lateral segment of the left lobe In the umbilical fossa the selective distribution of tributaries (7) to the middle hepatic duct is fully comparable with that frequently observed by the author in arterial branches

Drainage of the caudate lobe is typical the papillary process being drained by a branch of the left hepatic duct the caudate process by a branch of the right hepatic duct Short parallel type of union of the cystic duct with the hepatic duct they being *united for 2 cm* HD 1 5 cm CD 5 cm

high (Fig 154) When of the last type the angle between the right and left branches of the hepatic duct is very wide or nearly obliterated (Fig 160) When the union of the right and left hepatic ducts is low a Y shaped fork is formed through which the right hepatic artery a branch of it or even the cystic artery may pass An intrahepatic union of the right and left hepatic ducts i e formation of the hepatic duct inside the liver was not observed in the specimens examined It has however repeatedly been observed by other investigators more recently by Thompson (1933)

In his extrahepatic dissections Schroy noted that the right hepatic duct divides into an upper (anterior) and a *lower (posterior) main branch* [later changed by Healey and Schroy to the anterior and the posterior segmental ducts] both of which usually undergo one or more subdivisions before entering the liver (Fig 156) The upper branch courses upward and forward to the proximal (neck) region of the gallbladder bed and the right side of the quadrate lobe Here it receives from 1 to 7 ducts from the right side of the liver (average 3) In 14 cases it received branches from the quadrate lobe and in 13 cases a long fine filamentous duct from the gallbladder bed (Fig 160) The number of extrahepatic bile ducts draining into the *right* branch of the common hepatic duct varied from 3 to 17 (average 8) In 40 cases (80%) the right hepatic duct received from 1 to 10 tributaries and in 10 cases (20%) from 11 to 17

The lower branch of the right hepatic duct according to Schroy courses downward and backward to the right extremity of the porta hepatis where it *divides extrahepatically into* 2 to 11 branches (Fig 162) It often enters into a *fissured area* situated below the gallbladder the fissure being made by a lateral extension of the porta hepatis

As it courses through the fissure it intermittently gives branches to its side walls before sinking into the liver as a main trunk (Figs 154 160) In this position it may be crossed by the cystic duct in the identification of which during cholecystectomy it may readily be injured especially on deep probing with resultant postoperative jaundice of unknown origin (Fig 161)

Variations from the pattern in which the right hepatic duct divides into an upper (anterior) and lower (posterior) main branch comprise instances in which there are two distinct main right hepatic branches from the common hepatic duct (Figs 155 161) Surgically considered this is a very important anatomical fact for in the past an extra large right hepatic branch joining the hepatic duct has been considered as an accessory right hepatic duct

Regarding the left hepatic duct Schroy stated that Typically the left hepatic duct after receiving the middle hepatic duct and a duct from the papillary process of the caudate lobe divides extrahepatically into two main branches an upper (anterior) and a lower (posterior) branch (Fig 153) The upper branch courses forward and after crossing the umbilical fossa usually subdivides into 2 to 6 terminal branches before entering the left lobe of the liver It commonly receives one or more branches from the liver substance underlying the umbilical fossa and often receives a branch from the quadrate lobe (Figs 153 154)

The lower (posterior) left branch of the hepatic duct courses backward and likewise becomes subdivided into 2 to 4 terminal branches (average 2) before entering the left lobe of the liver (Fig 154) In instances (11%) it is the site of drainage of a major duct from the papillary process of the caudate lobe (Fig 155) Ducts coming from the liver substance underlying the fossa for the

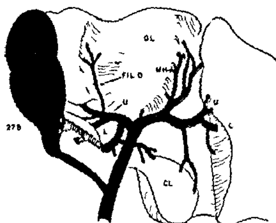


Fig 160 Pattern showing typical drainage of the area behind portal fissure by a lower (posterior) division of the right hepatic duct which may be injured upon deep probing The right hepatic duct is very short dividing into an upper (U) and a lower (L) branch As judged from casts these *purportedly are the anterior and the* posterior segmental ducts of the right lobe A filamentous duct (Fil D) from the gall bladder bed joins the anterior segmental duct and readily could have been torn in the removal of the gallbladder with resultant postoperative jaundice

The middle hepatic duct (MH) draining the quadrate lobe (medial segment of the left lobe) is a branch of the left hepatic duct and receives a small tributary from the lateral segment of the left lobe the main drainage of which is accomplished by the upper (U) and the lower (L) division *i e inferior and superior area ducts of the* lateral segment of the left lobe as judged by casts In the umbilical fossa the middle hepatic duct exhibits an anastomosis as is typically the case with branches of the middle hepatic artery

The caudate lobe (CL) has a very common type of biliary drainage to wit the papillary process being drained by a branch of the left hepatic duct the caudate process by a branch of the posterior segmental duct of the right hepatic duct Comparable patterns are to be found in the arterial vascularization of the caudate lobe as often illustrated in this atlas HD 1 cm CD 3 5 cm

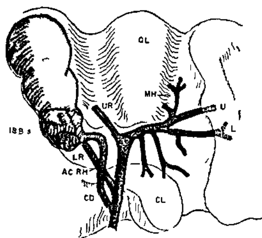


Fig 161 Pattern showing 2 main right hepatic ducts of which the lower is a so called accessory right hepatic duct As judged from the casts of Healey and Schroy the sample represents an instance *in which the* anterior segmental duct (UR) and the posterior segmental duct (LR) of the respective anterior and posterior seg *ments of the right lobe did not unite to* form a main right hepatic trunk but joined the hepatic duct separately Point of union of the posterior segmental duct (LR) was sufficiently caudad of the (UR) anterior segmental duct (20 mm) to place the duct into the confines of the cystic triangle of Calot where as a so called accessory he patic duct (AcHD) it could have been manipulated by deep probing in the iso *lation of the cystic duct*

The middle hepatic duct (MH) draining the quadrate lobe (medial segment of the left lobe) joins the upper (U) division i e inferior area duct of the lateral segment of the left lobe the lower (L) division repre senting the purported superior area duct of the lateral segment

The caudate lobe (CL) is drained entirely by branches from the trunk of the left he *patic duct The extrahepatic biliary tree* has 18 terminal tributaries some coming from the umbilical fossa others from the fossa for the ligamentum venosum HD 4 cm CD 2 5 cm

In the accompanying illustrations note the variable number of terminal bile ducts (13 to 53) leaving *the liver the situation* being comparable with the variable num ber of terminal hepatic arteries entering the liver substance

ductus venosus often join it (Fig 161)

Variations from the typical pattern comprised one in which the lower (pos terior) branch from the left lobe joined the right hepatic duct This lower *branch can readily be interpreted as an* accessory left hepatic duct which joined the right hepatic duct Another varia tion was the instance in which an acces sory left hepatic duct joined the com mon hepatic duct (Fig 156) Actually it is a case of two left hepatic ducts i e instead of having one main left hepatic duct there are *two main* left hepatic ducts The two cited cases definitely disprove the viewpoint that accessory he patic ducts are restricted *to the right side* of the liver

In addition to draining the left lobe of the liver the quadrate lobe the area for the umbilical fossa and the area of the fossa for the ductus venosus the left hepatic trunk or its lower division in nearly all instances (94%) received one *or more ducts from the* caudate lobe In about 15 per cent the left hepatic duct drained both caudate and papillary processes *of the caudate lobe (Fig 157)* It drained the papillary process alone in 85 per cent of the cases (Fig 159) In 40 cases ducts from *the papillary* process entered either the trunk of the left he patic duct or its lower division

Accessory Hepatic Ducts In respect to these Schroy reported that Early division of the common hepatic duct or conversely stated late confluence of the biliary ducts from the right side of the liver are the source of so called accessory hepatic ducts It is commonly stated that the latter may join the common hepatic *duct (Fig 161) the right hepatic* duct the cystic duct or even the common bile duct below the site of origin of the cystic *duct It is quite obvious from the figures* on the formation of the right hepatic duct that the term accessory is purely arbitrary How *high must a branch* of

the hepatic or its main right branch be so that it will not be called an accessory hepatic duct.

Ultimately the right hepatic duct divides into many branches. It is because of the ever varying pattern in the mode of branching of the right hepatic duct that there is absolutely no uniformity as to the percentage incidence of accessory bile ducts, data in the literature varying from 2 to 20 per cent. In the past an arbitrary standard has been established by regarding only those bile ducts as accessory which course through the cystic triangle to join the hepatic duct or its right branch, those which join the cystic duct or common bile duct and those which course relatively superficial in the gallbladder bed.

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As final conclusions to this atlas it may be stated that it is now established definitely that (1) both the right hepatic artery and the right hepatic duct divide into an anterior and a posterior segmental branch for the respective anterior and posterior segmental divisions of the right lobe (2) the left hepatic artery and the left hepatic duct ultimately divide into a superior and an inferior area branch of the lateral segment of the left lobe, the left hepatic duct having previously given off the middle hepatic duct (3) the middle hepatic artery and the middle hepatic duct are concerned with the quadrate lobe (medial segment of the left lobe) (4) the right and the left hepatic artery and bile ducts are concerned with the caudate lobe.

There remains however a very important problem to be solved, to wit the significance of the numerous twig-like extrahepatic ramifying terminal branches given off by the hepatic arteries and the bile ducts to the liver substance. In the plastic casts of hepatic arteries and ducts made by Healey and Schroy

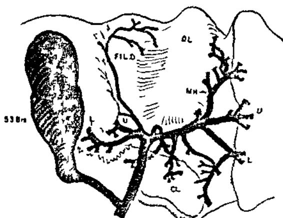


Fig 162 The common hepatic duct has a total of 53 extrahepatic tributaries, the maximal number encountered. The maximal number of terminal hepatic arteries encountered by the author in 200 extrahepatic dissections was 63, showing that there is a marked parallelism between the selective distribution of bile ducts and arteries to peripheral regions of the liver under Glisson's capsule.

The right hepatic duct is very short as it divides nearly immediately into its purported anterior (U) and posterior (L) segmental duct of the right lobe. The posterior segmental duct enters the fissured area under the gallbladder and like the comparable posterior segmental artery gives off branches to the side walls of the fissure here exposed by removal of omental tissue. A subvesicular duct with ramifying tributaries in the gallbladder bed joins the short right hepatic duct. In cholecystectomy it could be overlooked readily and torn with resultant jaundice of unknown origin.

The middle hepatic duct from the quadrate lobe (medial segment) drains into the purported inferior area branch (U) of the left hepatic duct at the junction point of the superior area branch (L) of the lateral segment. One of the subdivisions of the main inferior area duct of the lateral segment joins the middle hepatic duct (MH) and duplicates in this respect arterial arrangement.

The caudate lobe (CL) is drained entirely by the left hepatic duct via 3 branches, these as judged from casts being 1 for the caudate process, 1 for the left and 1 for the right side of the caudate lobe proper. HD 4.5 cm. CD 5.5 cm.

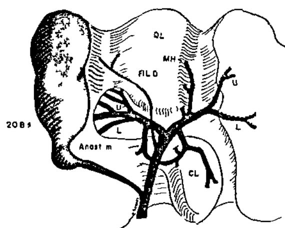


FIG 163 The tributaries to the right and left hepatic ducts which drain the caudate lobe are anastomosed extrahepatically A filamentous (accessory) bile duct emerges from the gallbladder bed to join the common hepatic duct The right hepatic duct divides into an upper (U) and a lower (L) branch these as judged from casts representing the anterior and the posterior segmental ducts for the respective anterior and posterior segments of the right lobe Both ducts subdivide before entering the liver

The left hepatic duct receives the middle hepatic duct (MH) draining the quadrate lobe or medial segment of the left lobe After crossing the umbilical fossa it divides into an upper (U) and lower (L) terminal branch these as judged from casts being the inferior and the superior area branches of the lateral segment of the left lobe The subvesicular duct from the gallbladder bed joins the common hepatic duct its most frequent mode of union being with the right hepatic duct

The caudate lobe (CL) is drained via 3 routes As judged from casts these are a tributary from the caudate process joins the right hepatic duct and a tributary from the left half and the right half of the papillary process respectively considered joins the left hepatic duct

Note There is a definite anastomosis between the caudate branches derived from the right and the left hepatic ducts thus confirming the statement of Longmire that in the caudate region such anastomosis exists In the plastic casts of the intrahepatic biliary tree Healey and Schroy never observed an intrahepatic anastomosis between caudate branches

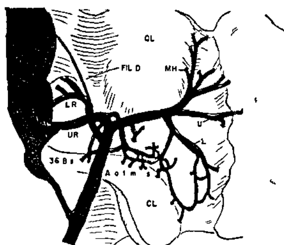


FIG 164 Clear cut and extensive anastomoses between the branches of the right and the left hepatic ducts which drain the caudate lobe Judged from variants observed by Healey and Schroy in plastic casts the point of union of the 2 right hepatic ducts is reversed in the sense that the lower right hepatic duct (LR) is the purported anterior segmental duct while the upper right hepatic duct (UR) represents the posterior segmental duct of the right lobe

The upper (U) division of the left hepatic duct i e purported inferior area branch of the lateral segment of the left lobe receives the middle hepatic duct (MH) from the quadrate lobe or medial segment The lower division (L) i e purported superior area branch receives tributaries from the caudate lobe

The caudate lobe is drained via 3 routes In 6 places the caudate tributaries are anastomosed thus confirming Longmire's contention that in the caudate region bile ducts from the right and the left lobes of the liver are anastomosed This extrahepatic anastomosis of bile ducts is comparable with that repeatedly observed by the author in caudate arteries In contrast with extrahepatic conditions Healey and Schroy never observed an anastomosis between bile ducts of the right and the left lobes inside the liver *Whether such intrahepatic anastomosis exists in bile ducts of dimensions less than those observed in plastic casts is as yet a major unsolved problem* A finer technic reaching out to capillaries should be essayed thus relaying the problem to the field of histology wherein Mall's work (1906) is of pioneer interest whereas *the contributions of Knisely (1948)* and of Elias (1953) afford some of the latest approaches

Veins of the Liver Portal Vein

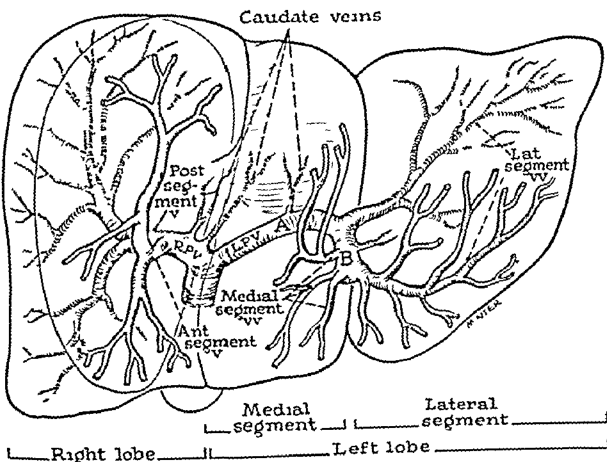


Fig 169 Typical intrahepatic distribution of the portal vein in the human liver as seen in a vinyl acetate corrosion cast The branches of the portal vein inside the liver are arranged segmentally

The right trunk or the main right branch of the portal vein (RPV) usually is regarded as a continuation of the common portal vein situated toward the right end of the porta hepatis Like divisions of the hepatic artery and the common bile duct it divides into an anterior and a posterior segmental vein each of which as a rule becomes subdivided into a superior and an inferior area branch The left trunk or the main left branch of the portal vein (LPV) is considerably longer and narrower than the right trunk as seen in most illustrations of this atlas After an oblique course of several centimeters (2 to 4) it makes a characteristic 90 bend in a caudolateral direction As shown by Glisson Rex Melnikoff Hjortsjo Elias and Petty it usually exhibits 2 portions a pars transversa (A) located in the porta hepatis and a pars umbilicalis (B) which lies deep in the umbilical (left sagittal) fossa where it constitutes the bended section

The lateral segment of the left lobe in most cases has 2 main branches (lat segment vv) one arising from the left side of the bend of the left portal trunk the other more distally from the left side of the pars umbilicalis (see atlas illustrations) The medial segment (quadrate lobe) of the liver receives branches (medial segment vv) from the right side of the umbilical section of the left portal vein Predominantly the 2 superior and the 2 inferior area branches for the medial segment arise from the umbilical portion of the left portal vein via a common stem (See author s drawings)

The caudate lobe receives branches of the portal vein in a manner comparable in origin and distribution with that of the caudate arteries and the bile ducts Usually there are 3 caudate veins 1 for the caudate process from the right portal trunk and 2 branches for the papillary process from the left portal trunk (From Healey Fig 3 after Healey and Schroy In J Intern nat Coll Surgeons 22 516 Nov 1954)

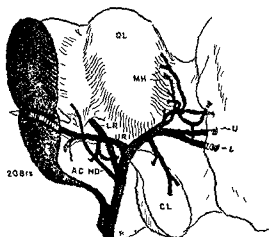


Fig 159 Pattern with 2 main right hepatic ducts with a filamentlike accessory duct joining the common hepatic duct As judged from casts of the intrahepatic biliary tree the anterior segmental duct (LR) joined the hepatic duct separately at a low hilar position and oddly so it being the first branch The right hepatic duct (UR) entering the fissured area under the gallbladder is the purported posterior segmental duct of the posterior segment of the right lobe It is crossed by the anterior segmental duct and by an accessory hepatic duct (AcHD) which coming from the gallbladder bed descends into the confines of the cystic triangle of Calot where it could have been subject to surgical harm in a cholecystectomy with resultant postoperative leakage of bile and peritonitis

The left hepatic duct receives the middle hepatic duct (MH) which in addition to draining the quadrate lobe (medial segment) receives small tributaries from the lateral segment of the left lobe The left hepatic duct divides into its typical terminal branches (U L) these representing the purported inferior and superior area ducts of the lateral segment of the left lobe In the umbilical fossa the selective distribution of tributaries (7) to the middle hepatic duct is fully comparable with that frequently observed by the author in arterial branches

Drainage of the caudate lobe is typical the papillary process being drained by a branch of the left hepatic duct the caudate process by a branch of the right hepatic duct Short parallel type of union of the cystic duct with the hepatic duct they being united for 2 cm HD 4 5 cm CD 3 cm

high (Fig 154) When of the last type *the angle between the right and left* branches of the hepatic duct is very wide or *nearly obliterated* (Fig 160) When the union of the right and left hepatic ducts is low, a Y shaped fork is formed through which the right hepatic artery a branch of it or even the cystic artery may pass An intrahepatic union of the right and left hepatic ducts i e formation of the hepatic duct inside the liver was not observed in the specimens examined It has however repeatedly been observed by other investigators more recently by Thompson (1933)

In his extrahepatic dissections Schroy noted that the right hepatic duct divides into an upper (anterior) and a lower (posterior) main branch [later changed by Healey and Schroy to the *anterior* and the *posterior* segmental ducts] both of which usually undergo one or more subdivisions before entering the liver (Fig 156) The upper branch courses upward and forward to the proximal (neck) region of the gall bladder bed and the right side of the quadrate lobe Here it receives from 1 to 7 ducts from the right side of the liver (average 3) In 14 cases it received branches from the quadrate lobe and in 13 cases a long fine *filamentous duct from* the gallbladder bed (Fig 160) The number of extrahepatic bile ducts draining into the right branch of the common hepatic duct varied from 3 to 17 (average 8) In 40 cases (80%) the right hepatic duct received from 1 to 10 tributaries and in 10 cases (20%) from 11 to 17

The lower branch of the right hepatic duct according to Schroy courses downward and backward to the right extremity of the porta hepatis where it divides extrahepatically into 2 to 11 branches (Fig 162) It often enters into a *fissured area* situated below the gall bladder the fissure being made by a lateral extension of the porta hepatis

As it courses through the fissure it intermittently gives branches to its side walls before sinking into the liver as a main trunk (Figs 151 160) In this position it may be crossed by the cystic duct in the identification of which during cholecystectomy it may readily be injured especially on deep probing with resultant postoperative jaundice of unknown origin (Fig 161)

Variations from the pattern in which the right hepatic duct divides into an upper (anterior) and lower (posterior) main branch comprise instances in which there are two distinct main right hepatic branches from the common hepatic duct (Figs 155 161) Surgically considered this is a very important anatomical fact for in the past an extra large right hepatic branch joining the hepatic duct has been considered as an accessory right hepatic duct

Regarding the left hepatic duct Schroy stated that Typically the left hepatic duct after receiving the middle hepatic duct and a duct from the papillary process of the caudate lobe divides extrahepatically into two main branches an upper (anterior) and a lower (posterior) branch (Fig 153) The upper branch courses forward and after crossing the umbilical fossa usually subdivides into 2 to 6 terminal branches before entering the left lobe of the liver It commonly receives one or more branches from the liver substance underlying the umbilical fossa and often receives a branch from the quadrate lobe (Figs 153 154)

The lower (posterior) left branch of the hepatic duct courses backward and likewise becomes subdivided into 2 to 4 terminal branches (average 2) before entering the left lobe of the liver (Fig 154) In instances (14%) it is the site of drainage of a major duct from the papillary process of the caudate lobe (Fig 155) Ducts coming from the liver substance underlying the fossa for the

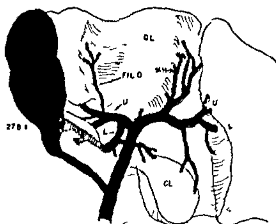


Fig 160 Pattern showing typical drainage of the area behind portal fissure by a lower (posterior) division of the right hepatic duct which may be injured upon deep probing The right hepatic duct is very short dividing into an upper (U) and a lower (L) branch As judged from casts these purportedly are the anterior and the posterior segmental ducts of the right lobe A filamentous duct (Fil D) from the gallbladder bed joins the anterior segmental duct and readily could have been torn in the removal of the gallbladder with resultant postoperative jaundice

The middle hepatic duct (MH) draining the quadrate lobe (medial segment of the left lobe) is a branch of the left hepatic duct and receives a small tributary from the lateral segment of the left lobe the main drainage of which is accomplished by the upper (U) and the lower (L) division i e inferior and superior area ducts of the lateral segment of the left lobe as judged by casts In the umbilical fossa the middle hepatic duct exhibits an anastomosis as is typically the case with branches of the middle hepatic artery

The caudate lobe (CL) has a very common type of biliary drainage to wit the papillary process being drained by a branch of the left hepatic duct the caudate process by a branch of the posterior segmental duct of the right hepatic duct Comparable patterns are to be found in the arterial vascularization of the caudate lobe as often illustrated in this atlas HD 1 cm CD 3 5 cm

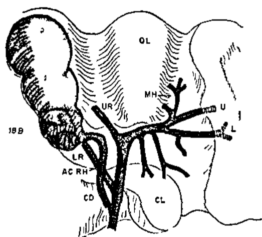


Fig 161 Pattern showing 2 main right hepatic ducts of which the lower is a so called accessory right hepatic duct As judged from the casts of Healey and Schroy the sample represents an instance in which the anterior segmental duct (UR) and the posterior segmental duct (LR) of the respective anterior and posterior segments of the right lobe did not unite to form a main right hepatic trunk but joined the hepatic duct separately Point of union of the posterior segmental duct (LR) was sufficiently caudad of the (UR) anterior segmental duct (20 mm) to place the duct into the confines of the cystic triangle of Calot where as a so called accessory hepatic duct (AcHD) it could have been manipulated by deep probing in the isolation of the cystic duct

The middle hepatic duct (MH) draining the quadrate lobe (medial segment of the left lobe) joins the upper (U) division i e inferior area duct of the lateral segment of the left lobe the lower (L) division representing the purported superior area duct of the lateral segment

The caudate lobe (CL) is drained entirely by branches from the trunk of the left hepatic duct The extrahepatic biliary tree has 18 terminal tributaries some coming from the umbilical fossa others from the fossa for the ligamentum venosum HD 4 cm CD 2 5 cm

In the accompanying illustrations note the variable number of terminal bile ducts (13 to 53) leaving the liver the situation being comparable with the variable number of terminal hepatic arteries entering the liver substance

ductus venosus often join it (Fig 161)

Variations from *the typical pattern* comprised one in which the lower (posterior) branch from the left lobe joined the right hepatic duct This lower branch can readily be interpreted as an accessory left hepatic duct which joined the right hepatic duct Another variation was the instance in which an accessory left hepatic duct joined the common hepatic duct (Fig 156) Actually it is a case of two left hepatic ducts i e instead of having one main left hepatic duct there are two main left hepatic ducts The two cited cases definitely disprove the viewpoint that accessory hepatic ducts are restricted to the right side of the liver

In addition to draining the left lobe of the liver the quadrate lobe the area *for the umbilical fossa and the area of* the fossa for the ductus venosus the left hepatic trunk or its lower division in nearly all instances (94%) received one or more ducts from *the caudate lobe* In about 15 per cent the left hepatic duct drained both caudate and papillary processes of the caudate lobe (Fig 157) It drained the papillary process alone in 85 per cent of the cases (Fig 159) In 40 cases ducts from the papillary process entered either the trunk of the left hepatic duct or its lower division

Accessory Hepatic Ducts In respect to these Schroy reported that Early division of the common hepatic duct or conversely stated late confluence of the biliary ducts from the right side of the liver are the source of so called accessory hepatic ducts It is commonly stated that the latter may join the common hepatic duct (Fig 161) the right hepatic duct the cystic duct or even the common bile duct below the site of origin of the cystic duct It is quite obvious from the figures on the formation of the right hepatic duct that the term accessory is purely arbitrary How high must a branch of

the hepatic or its main right branch be so that it will not be called an accessory hepatic duct?

Ultimately the right hepatic duct divides into many branches. It is because of the ever varying pattern in the mode of branching of the right hepatic duct that there is absolutely *no uniformity* as to the percentage incidence of accessory bile ducts, data in the literature *varying from 2 to 20 per cent*. In the past an arbitrary standard has been established by regarding only those bile ducts as accessory which course through the cystic triangle to join the hepatic duct or its right branch, those which join the cystic duct or common bile duct, and those which course relatively superficial in the gallbladder bed.

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As final conclusions to this atlas, it may be stated that it is now established definitely that (1) both the right hepatic artery and the right hepatic duct *divide into an anterior and a posterior segmental branch* for the respective anterior and posterior segmental divisions *of the right lobe*; (2) the left hepatic artery and the left hepatic duct ultimately divide into a superior and an *inferior area branch of the lateral segment* of the left lobe, the left hepatic duct having previously given off the middle hepatic duct; (3) *the middle hepatic artery* and the middle hepatic duct are concerned with the quadrate lobe (medial segment of the left lobe); (4) the right and the left hepatic artery and bile ducts are concerned with the caudate lobe.

There remains, however, a very important problem to be solved, to wit, the significance of the numerous twiglike extrahepatic ramifying terminal branches given off by the hepatic arteries and the bile ducts to the liver substance. In the plastic casts of hepatic arteries and ducts made by Healey and Schroy

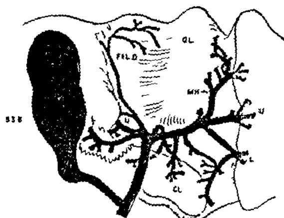


Fig. 162. The common hepatic duct has a total of 53 extrahepatic tributaries, the maximal number encountered. The maximal number of terminal hepatic arteries *encountered by the author in 200 extrahepatic dissections was 65*, showing that *there is a marked parallelism between the* selective distribution of bile ducts and arteries to peripheral regions of the liver under Glisson's capsule.

The right hepatic duct is very short, as it divides nearly immediately into its purported anterior (U) and posterior (L) *segmental duct of the right lobe*. The posterior segmental duct enters the fissured area under the gallbladder and, *like the comparable* posterior segmental artery, gives off branches to the side walls of the fissure here exposed by removal of omental tissue. A subvesicular duct with ramifying tributaries in the gallbladder bed joins the short right hepatic duct. In cholecystectomy it *could be overlooked readily and torn, with* resultant jaundice of unknown origin.

The middle hepatic duct from the quadrate lobe (medial segment) drains into the purported inferior area branch (U) of the left hepatic duct at the junction point of the superior area branch (L) of the lateral segment. One of the subdivisions of the main inferior area duct of the lateral segment joins the middle hepatic duct (MH) and duplicates in this respect arterial arrangement.

The caudate lobe (CL) is drained entirely *by the left hepatic duct* via 3 branches, these as judged from casts being 1 for the caudate process, 1 for the left and 1 for the right side of the caudate lobe proper. HD 4.5 cm. CD 5.5 cm.

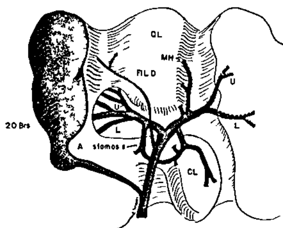


Fig 163 The tributaries to the right and left hepatic ducts which drain the caudate lobe are anastomosed extrahepatically A filamentous (accessory) bile duct emerges from the gallbladder bed to join the common hepatic duct The right hepatic duct divides into an upper (U) and a lower (L) branch these as judged from casts representing the anterior and the posterior segmental ducts for the respective anterior and posterior segments of the right lobe Both ducts subdivide before entering the liver

The left hepatic duct receives the middle hepatic duct (MH) draining the quadrate lobe or medial segment of the left lobe After crossing the umbilical fossa it divides into an upper (U) and lower (L) terminal branch these as judged from casts being the inferior and the superior area branches of the lateral segment of the left lobe The subvesicular duct from the gallbladder bed joins the common hepatic duct its most frequent mode of union being with the right hepatic duct

The caudate lobe (CL) is drained via 3 routes As judged from casts these are a tributary from the caudate process joins the right hepatic duct and a tributary from the left half and the right half of the papillary process respectively considered joins the left hepatic duct

Note There is a definite anastomosis between the caudate branches derived from the right and the left hepatic ducts thus confirming the statement of Longmire that in the caudate region such anastomosis exists In the plastic casts of the intrahepatic biliary tree Healey and Schroy never observed an intrahepatic anastomosis between caudate branches

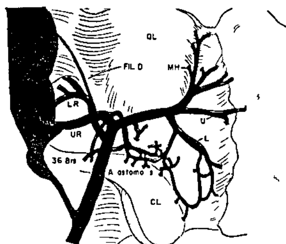


Fig 164 Clear cut and extensive anastomoses between the branches of the right and the left hepatic ducts which drain the caudate lobe Judged from variants observed by Healey and Schroy in plastic casts the point of union of the 2 right hepatic ducts is reversed in the sense that the lower right hepatic duct (LR) is the purported anterior segmental duct while the upper right hepatic duct (UR) represents the posterior segmental duct of the right lobe

The upper (U) division of the left hepatic duct i e purported inferior area branch of the lateral segment of the left lobe receives the middle hepatic duct (MH) from the quadrate lobe or medial segment The lower division (L) i e purported superior area branch receives tributaries from the caudate lobe

The caudate lobe is drained via 3 routes In 6 places the caudate tributaries are anastomosed thus confirming Longmire s contention that in the caudate region bile ducts from the right and the left lobes of the liver are anastomosed This extrahepatic anastomosis of bile ducts is comparable with that repeatedly observed by the author in caudate arteries In contrast with extrahepatic conditions Healey and Schroy never observed an anastomosis between bile ducts of the right and the left lobes inside the liver *Whether such intrahepatic anastomosis exists in bile ducts of dimensions less than those observed in plastic casts is as yet a major unsolved problem* A finer technic reaching out to capillaries should be assayed thus relaying the problem to the field of histology wherein Mall s work (1906) is of pioneer interest whereas the contributions of Knisely (1948) and of Elias (1953) afford some of the latest approaches

Veins of the Liver: Portal Vein

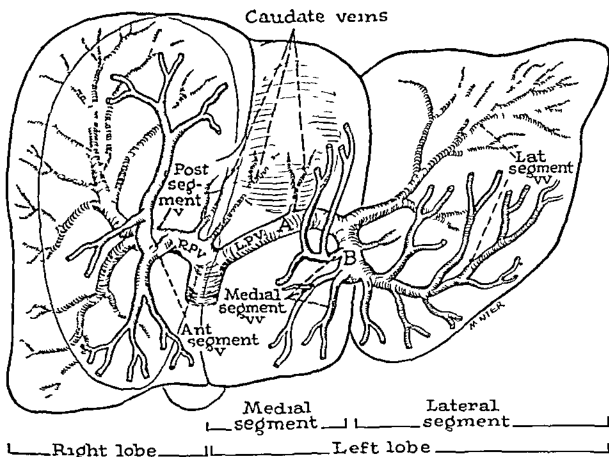


Fig. 165. Typical intrahepatic distribution of the portal vein in the human liver as seen in a vinyl acetate corrosion cast. The branches of the portal vein inside the liver are arranged segmentally.

The right trunk or the main right branch of the portal vein (RPV) usually is regarded as a continuation of the common portal vein situated toward the right end of the porta hepatis. Like divisions of the hepatic artery and the common bile duct, it divides into an anterior and a posterior segmental vein, each of which as a rule becomes subdivided into a superior and an inferior area branch. The left trunk or the main left branch of the portal vein (LPV) is considerably longer and narrower than the right trunk, as seen in most illustrations of this atlas. After an oblique course of several centimeters (2 to 4), it makes a characteristic 90° bend in a caudolateral direction. As shown by Glisson, Rex, Melnikoff, Hjortsjo, Elias and Petty, it usually exhibits 2 portions: a pars transversa (A) located in the porta hepatis and a pars umbilicalis (B), which lies deep in the umbilical (left sagittal) fossa, where it constitutes the bended section.

The lateral segment of the left lobe in most cases has 2 main branches (lat. segment vv.), one arising from the left side of the bend of the left portal trunk, the other more distally from the left side of the pars umbilicalis (see atlas illustrations). The medial segment (quadrate lobe) of the liver receives branches (medial segment vv.) from the right side of the umbilical section of the left portal vein. Predominantly the 2 superior and the 2 inferior area branches for the medial segment arise from the umbilical portion of the left portal vein via a common stem. (See author's drawings.)

The caudate lobe receives branches of the portal vein in a manner comparable in origin and distribution with that of the caudate arteries and the bile ducts. Usually there are 3 caudate veins: 1 for the caudate process from the right portal trunk and 2 branches for the papillary process from the left portal trunk. (From Healey, Fig. 3, after Healey and Schroy. In: J. Internat. Coll. Surgeons 22:546, Nov. 1954.)

Veins of the Liver Hepatic Vein

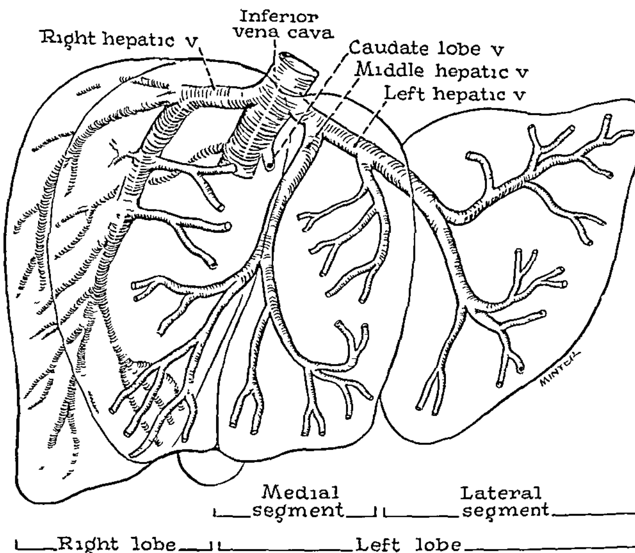


Fig 166 Prevailing pattern of the distribution of the hepatic vein in the human liver as demonstrable in a vinyl acetate (plastic) corrosion cast made by Healey and Schroy at the Daniel Baugh Institute of Anatomy Jefferson Medical College under the directorship of George Allen Bennett M D Professor of Anatomy and Dean of the College

In contrast with the segmental arrangement of the hepatic arteries the bile ducts and the portal vein branches the arrangement of the hepatic veins inside the liver is definitely *not segmental As demonstrable in plastic casts the hepatic veins lie in fissured areas i e in intersegmental planes* this topographic relationship being comparable with that of the pulmonary veins in the lung which likewise are not distributed segmentally Clear cut fissures definitely demarcating the segments of the liver are visible only when the hepatic artery the bile duct and the portal vein are injected for if additively the hepatic veins are injected no fissures can be seen these being occupied by the hepatic veins

Like the hepatic artery the hepatic vein has 3 main branches the right the left and the middle hepatic veins (Rex) The 3 vessels open obliquely and directly into the inferior vena cava constituting the latter s largest visceral tributaries As reported by Healey (1951) the right hepatic vein lies in the right segmental fissure the middle hepatic vein in the lobar fissure and the left hepatic vein in the upper part of the left segmental fissure Each of the 3 hepatic veins drains adjacent liver segments The right hepatic vein drains the entire posterior segment plus the superior area of the anterior segment of the right lobe The middle hepatic vein drains the inferior area of the anterior segment of the right lobe plus the inferior area of the medial segment The left hepatic vein drains the entire lateral segment of the left

lobe plus the superior area of the medial segment

The right hepatic vein, a remnant of the cardiac portion of the primitive right omphalomesenteric vein of the embryo (Mall), opens directly into the right side of the inferior vena cava as it lies in the fossa venae cavae. The middle and the left hepatic veins in most cases unite to form a common trunk before entering the vena cava (as shown here and as first ascertained by Rex in crude corrosion casts in 1888).

In addition to the 3 main hepatic veins there are one or more constant small hepatic veins that drain the caudate lobe and a variable number of inconstant branches that drain part of the posterior segment of the right lobe.

The two systems of venous channels, portal and hepatic veins, are interdigitated in their branches as first shown by Glisson in his *Anatomia hepatis* (1654) and substantiated by Melnikoff of St Petersburg in 1921. The patterns are comparable with those obtained when palm to palm the fingers of each hand are made to cross each other in midline as illustrated by Elias and Petty (Am J Anat 90 59–111 1952). (From Healey Fig 1 after Healey and Schroy In J Internat Coll Surgeons 22 517 Nov 1954.)

The problem of the venous circulation of the liver (portal and hepatic) is far from being solved. Plastic casts give but an outline of existent patterns on which a major work is now under investigation. Casts under study show the variability of the venous system to such an extent as to make surgeons aware that there is no uniform procedure of venous drainage.

The venous circulation of the liver offers the following investigative problems (1) direct portohepatic anastomoses (shunts) existent in cirrhosis but doubtful normally (2) rapidity of the circulation of the blood through the right and the left lobes of the liver as once claimed by Serege and Soula (1905) (3) vascular independence of the portal vein in the right and the left lobes of the liver as claimed by Looten (1908) in injected bodies of infants (4) relation between the portoglissonean venous system and that of the subhepatic venous channels as advocated by Sabourin (1900) (5) are the intrahepatic subhepatic veins nothing else but emanations from the capsule of Glisson? (6) do the veins of the portal canal end directly into the subhepatic Glisson veins?

where all the liver tissue was removed by the corrosion method with concentrated hydrochloric acid these small branches obviously are not demonstrable, no demarcation lines of the peripheral contours of the liver substance being discernible, they having been destroyed by the technic used. The terminal extrahepatic branches however are plainly visible in gross extrahepatic dissection as evidenced in the author's dissections in 200 bodies of arteries injected with a carmine red starch solution and as evidenced in Schroy's dissections of bile ducts injected with a vinyl acetate plastic compound in 50 specimens.

Glauser of the University of Pennsylvania (1953) in a study of fresh human livers in which small branches of the hepatic artery were injected with a radiopaque material showed by means of roentgenograms that every small hepatic branch has a selective distribution within the liver substance, i e every hepatic artery is an end artery supplying but one pyramidal lobe. A similar intrahepatic distribution is to be expected regarding the small bile ducts depicted in the illustrations of Schroy, every bile duct draining a specific area of the liver substance. This important biologic problem awaits further investigative work and is correlated intimately with a greater problem, to wit the significance of the blood supply and the bile drainage at the peripheral region of the liver, which so far as arteries are concerned is seemingly different from that in the interior of the organ, Glisson's capsule and the underlying ramifying small arteries playing a largely unknown role in the hepatic arterial vascularization.

This descriptive atlas may well be concluded with the following admonition

> Those who have dissected many bodies have at least learned to doubt, whereas others who are ignorant of anatomy and pay no heed to it are in no doubt at all
>
> —Morgagni

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